# DOCUMENT RESUME

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ABSTRACT

This packet, part of the instructional materials for the Oregon apprenticeship program for millwright training, contains 17 modules covering electricity and electronics. The modules provide information on the following topics: basics of energy, atomic theory, electrical conduction, basics of direct current, introduction to circuits, reading scales, using a Volt-O-Meter, Ohm's Law, Power and Watt's Law, Kirchoff's Current Law, Kirchoff's Voltage Law, series resistive circuits, parallel resistive circuits, series-parallel resistive circuits, switches and relays, basics of alternating currents, and magnetism. Each module consists of a goal, performance indicators, student study guide, vocabulary, information sheets illustrated with line drawings, a task sheet with answers, a final test, and a student evaluation form. (KC)

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## APPRENTICESHIP

# MILLWRIGHT

## RELATED
## TRAINING MODULES

2.1 - 2.17 ELECTRICITY/ELECTRONICS

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# APPRENTICESHIP

## MILLWRIGHT
## RELATED TRAINING MODULES

### SAFETY

1.1 General Safety
1.2 Hand Tool Safety
1.3 Power Tool Safety
1.4 Fire Safety
1.5 Hygiene Safety
1.6 Safety and Electricity
1.7 Fire Types and Prevention
1.8 Machine Safeguarding (includes OSHA Handbook)

### ELECTRICITY/ELECTRONICS

2.1 Basics of Energy
2.2 Atomic Theory
2.3 Electrical Conduction
2.4 Basics of Direct Current
2.5 Introduction to Circuits
2.6 Reading Scales
2.7 Using a V.O.M.
2.8 OHM'S Law
2.9 Power and Watt's Law
2.10 Kirchoff's Current Law
2.11 Kirchoff's Voltage Law
2.12 Series Resistive Circuits
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5.14 Drafting, Machine Features
5.15 Drafting, Measurement
5.16 Drafting, Visualization

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6.2 Feedback
6.3 Individual Strengths
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6.5 Group Problem Solving
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7.7 Boilers - Heat Recovery Systems
7.8 Boilers - Instruments and Controls
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9.2 Pumps - Applications
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9.4 Pumps - Calculating Heat and Flow
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9.6 Pumps - Monitoring and Troubleshooting
9.7 Pumps - Maintenance

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10.2 Combustion - Types of Fuel
10.3 Combustion - Air and Fuel Gases
10.4 Combustion - Heat Transfer
10.5 Combustion - Wood

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11.2 Generators - Operation

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16.3 Additional and Subtraction of Common Fraction and Mixed Numbers
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17.10 Hydraulics - Forces, Area, Pressure
17.11 Hydraulics - Conductors and Connectors
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## METALLURGY

18.1 Included are ILS packets:
  W 3010
  W 3011-1
  W 3011-2
  MS 9001 (1-3-4-8-9-6-7-5-2-9)
  MS 9200, 9201

## POWER DRIVES

19.1 101. A-B-C-D-E
  102. C-D-E
  103. B-C-D-E
  104. A-C-E-F-G-H-I-J
  107. A
  108. A

## WELDING

20.1 602. A-B-C-D-G-I-L-M
  603. A-B-F-G-I
  W. 3011-1 refer to Mettallurgy 18.1
  WE. MA-18

# MILLWRIGHT
# SUPPLEMENTARY REFERENCE DIRECTORY

Note: All reference packets are numbered on the upper right-hand corner of the respective cover page.

| Supplementary Packet # | Description | Related Training Module | |
|---|---|---|---|
| 1.8 | Concepts & Techniques of Machine Safeguarding, U.S.D.L., O.S.H.A. | 1.8 | Machine Safeguarding |
| 12.1 | Correspondence Course, Lecture 1, Sec. 2, Steam Generators, Types of Boilers I, S.A.I.T., Calgary, Alberta, Canada | 7.1 | Boilers, Fire Tube Type |
| 12.2 | Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Types of Boikers II, S.A.I.T., Calgary, Alberta, Canada | 7.2 | Boilers, Water Tube Type |
| 12.3 | Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Boiler Construction & Erection, S.A.I.T., Calgary, Alberta, Canada | 7.3 | Boilers, Construction |
| 12.4 | Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fittings II, S.A.I.T., Calgary, Alberta, Canada | 7.4 | Boilers, Fittings |
| 12.4 | Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fitting I, S.A.I.T., Calgary, Alberta, Canada | 7.4 | Boilers, Fittings |
| 12.5 | Correspondence Course, Lecture 10, Sec. 2, Steam Generation, Boiler Operation, Maintenance, Inspection, S.A.I.T., Calgary, Alberta, Canada | 7.5 | Boilers, Operation |
| 12.7 | Correspondence Course, Lecture 3, Sec. 2, Steam Generation, Boiler Details, S.A.I.T., Calgary, Alberta, Canada | 7.7 | Boilers Heat Recovery Systems |
| | | PUMPS | |
| 13.1 | Correspondence Course, Lecture 9, Sec. 2, Steam Generator, Power Plant Pumps, S.A.I.T., Calgary, Alberta, Canada | 9.1 | Types & Classifications |
| 13.2 | | 9.2 | Applications |
| 13.4 | | 9.4 | Calculating Heat & Flow |
| 13.6 | | 9.6 | Monitoring & Troubleshooting |
| 13.7 | | 9.7 | Maintenance |
| 13.3 | Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Pumps, S.A.I.T., Calgary, Alberta, Canada | 9.3 | Construction |
| 13.5 | | 9.5 | Operation |

| Supplementary Packet # | Description | Related Training Module |
|---|---|---|
| 14.3<br>12.8 | Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Steam Generator Controls, S.A.I.T., Calgary, Alberta, Canada | 14.3 Steam Transport<br>7.8 Boilers, Instruments & Controls |
| 14.4 | Correspondence Course, Lecture 11, Sec. 2, Steam Generators, Piping II, S.A.I.T., Calgary, Alberta, Canada | 14.4 Steam Purification |
| 15.1 | Correspondence Course, Lecture 1, Sec. 4, Prime Movers, & Auxiliaries, Steam Turbines, S.A.I.T., Calgary, Alberta, Canada | 8.1 Steam Turbines, Types |
| 15.2 | Correspondence Course, Lecture 4, Sec. 3, Prime Movers, Steam Turbines I, S.A.I.T., Calgary, Alberta, Canada | 8.2 Steam Turbines, Components |
| 15.3 | Correspondence Course, Lecture 2, Sec. 4, Prime Movers & Auxiliaries, Steam Turbine Auxiliaries, S.A.I.T., Calgary, Alberta, Canada | 8.3 Steam Turbines, Auxiliaries |
| 15.4 | Correspondence Course, Lecture 6, Sec. 3, Prime Movers, Steam Turbine Operation & Maintenance, S.A.I.T., Calgary, Alberta, Canada | 8.4 Steam Turbines, Operation & Maintenance |
| 15.5 | Correspondence Course, Lecture 8, Sec. 3, Prime Movers, Gas Turbines, S.A.I.T., Calgary, Alberta, Canada | 8.5 Gas Turbines |
| 16.2 | Boilers Fired with Wood & Bark Residues, D.D. Junge, F.R.L., O.S.U., 1975 | 10.2 Combustion Types of Fuel |
| 16.2 | Correspondence Course, Lecture 5, Sec. 2, Steam Generators, Fuel Combustion, S.A.I.T., Calgary, Alberta, Canada | 10.2 Combustion Types of Fuel |
| 16.3 | Correspondence Course, Lecture 5, Sec. 2, Plant Services, Fuel & Combustion, S.A.I.T., Calgary, Alberta, Canada | 10.3 Combustion Air & Fuel Gases |
| 17.1 | Correspondence Course, Lecture 12, Sec. 3, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada | 12.1 Feedwater, Types & Operation |
| 17.2 | Correspondence Course, Lecture 12, Sec. 2, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada | 12.2 Feedwater, Water Treatments |

| Supplementary Packet # | Description | Related Training Module |
|---|---|---|
| 17.3 | Correspondence Course, Lecture 7, Sec. 2, Steam Generators, Boiler Feedwater Treatment, S.A.I.T., Calgary, Alberta, Canada | 12.3 Feedwater, Testing |
| 18.1 | Correspondence Course, Lecture 2, Sec. 5, Electricity, Direct Current Machines, S.A.I.T., Calgary, Alberta, Canada | 11.1 Generators, Types & Construction |
| 18.1<br>18.2 | Correspondence Course, Lecture 4, Sec. 5, Electricity, Alternating Current Generators, S.A.I.T., Calgary, Alberta, Canada | 11.1 Generators. Types & Construction<br>18.2 Generators, Operation |
| 19.1 | Correspondence Course, Lecture 5, Sec. 4, Prime Movers & Auxiliaries, Air Compressor I, S.A.I.T., Calgary, Alberta, Canada | 13.1 Air Compressors, Types |
| 19.1 | Correspondence Course, Lecture 6, Sec. 4, Prime Movers & Auxiliaries, Air Compressors II, S.A.I.T., Calgary, Alberta, Canada | 13.1 Air Compressors, Types<br>13.2 Air Compressors, Operation & Maintenance |
| 20.1 | Basic Electronics, Power Transformers, EL-BE-51 | 15.4 Transformers |
| 21.1 | Correspondence Course, Lecture 6, Sec. 5, Electricity, Switchgear & Circuit, Protective Equipment, S.A.I.T., Calgary, Alberta, Canada | 15.3 Circuit Protection |
| 22.1 | Correspondence Course, Lecture 10, Sec. 3, Prime Movers, Power Plant Erection & Installation, S.A.I.T., Calgary, Alberta, Canada | 15.1 Installation Foundations |

# RECOMMENDATIONS FOR USING TRAINING MODULES

The following pages list modules and their corresponding numbers for this particular apprenticeship trade. As related training classroom hours vary for different reasons throughout the state, we recommend that the individual apprenticeship committees divide the total packets to fit their individual class schedules.

There are over 130 modules available. Apprentices can complete the whole set by the end of their indentured apprenticeships. Some apprentices may already have knowledge and skills that are covered in particular modules. In those cases, perhaps credit could be granted for those subjects, allowing apprentcies to advance to the remaining modules.

We suggest the the apprenticeship instructors assign the modules in numerical order to make this learning tool most effective.

Modules 18.1, 19.1, and 20.1 have been omitted because they contain dated materials.

## SUPPLEMENTARY INFORMATION

## ON CASSETTE TAPES

Tape 1: Fire Tube Boilers - Water Tube Boilers and Boiler Manholes and Safety Precautions

Tape 2: Boiler Fittings, Valves, Injectors, Pumps and Steam Traps

Tape 3: Combustion, Boiler Care and Heat Transfer and Feed Water Types

Tape 4: Boiler Safety and Steam Turbines

NOTE: The above cassette tapes are intended as additional reference material for the respective modules, as indicated, and not designated as a required assignment.

INSTRUCTIONAL LEARNING SYSTEMS

# 2.1

## BASICS OF ENERGY

**Goal:**

The apprentice will be able to describe basic units of energy.

**Performance Indicators:**

1. Describe units of measurement.
2. Describe conversion of energy.
3. Describe potential energy.
4. Describe kinetic energy.
5. Describe energy efficiency.

# BASIC ELECTRONICS

## Basics of Energy
## EL-BE-02

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| Definitions and explanations of base units, energy, work, conversion of energy, and efficiency. | Solve problems dealing with energy. Answer questions about energy correctly. |

## Directions

Obtain the following:

Calculator

## Learning Activities

_____ Read the Key Words list.

_____ Read the Information Sheets.

_____ Do Task: Solve the Problems on the Problem Sheets.

_____ Do the Self-Test.

_____ Do the Final Test.

_____ Obtain Final Evaluation.

## Key Words

Base Unit: The term used to indicate the amount of something. As examples: Length is measured in feet (the foot is a base unit for length). Weight is measured in grams (the gram is a base unit for weight).

Efficiency: The relationship between the energy applied and the energy output (expressed in percent).

Energy: The ability to do work.

Force: Pressure or push on an object or particle.

Joule: Equal to the newton--the base unit for mechanical energy.

Load: The part of an electrical circuit where energy conversion takes place.

Newton: The base unit for force in the metric system--approximately .224 pounds of force.

Work: Force times distance.

# Information Sheet

## Energy and Work

If our car stalls in the street and we must push it to the curb by hand, we know that, as we are moving the car, pushing it is work. When we have moved the car to where we want it, the work is done. Work, then, is made up of two things. First, there is the push or force we place on the car in the direction we want it to go. Second, the car moves over a distance to a point where we want it to go. Force and distance make up work. The force must be enough to overcome the friction of the wheels and to raise the car over lumps in the roadway. Mathematically, the work done is equal to the force times the distance. The work energy symbol that we use when we calculate for work is the upper case W. The base unit of measure in the metric system for work is the joule.

To find the amount of work done in joules that it took to move the car to the curb, we must know the force used and the distance moved. If we pushed on the car with a pressure of 45 pounds and we moved the car 16 feet, we can figure out the work done by multiplying 45 times 16. However, the joule is a metric measure, so we must convert the force and the distance to metric terms before we can calculate the joules.

## The Metric Measure of Distance

The meter is the metric measure of distance. One meter is equal to approximately 39.4 inches. By converting, 16 feet is equal to approximately 5 meters. (16 x 12 = 192 inches. 192 ÷ 39.4 = 4.87 meters or approximately 5 meters.)

## The Metric Measure of Force

The metric measure of force is the newton. One newton is equal to approximately .224 pounds of force. By converting, 45 pounds is equal to 200 newtons. (45 ÷ .224 = 200)

Now we know that:

Work in joules = Force in newtons X Distance in meters

Let's find how many joules it took to move our car to the curb.

Given: Force (F)= 45 pounds or 200 newtons
Distance (d) = 16.4 feet or 5 meters

Find: Work (W) in joules

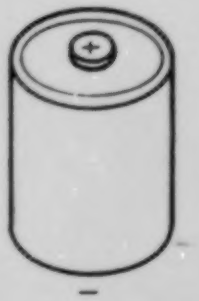
Solution: Work in joules = Force in newtons X Distance in meters
W = 200 newtons X 5 meters
W = 1000 joules

It took 1000 joules to move our car to the curb.

The measure of work done is also important when electricity supplies the energy to do the work. An example of work done using an electrical circuit is using the starter on the car. The energy from the battery must turn the starter motor to crank the engine. The work done by the battery can be expressed in joules.

## Energy Conversion

One of the basic laws of physics states that energy cannot be created or destroyed. Energy can be converted from one form to another. Energy is converted from one form to another in a battery. Inside the battery the chemical action that takes place produces stored electrical energy.



This stored energy is not doing any work. It is available for us to use to do work. We call this type of stored energy "potential energy."

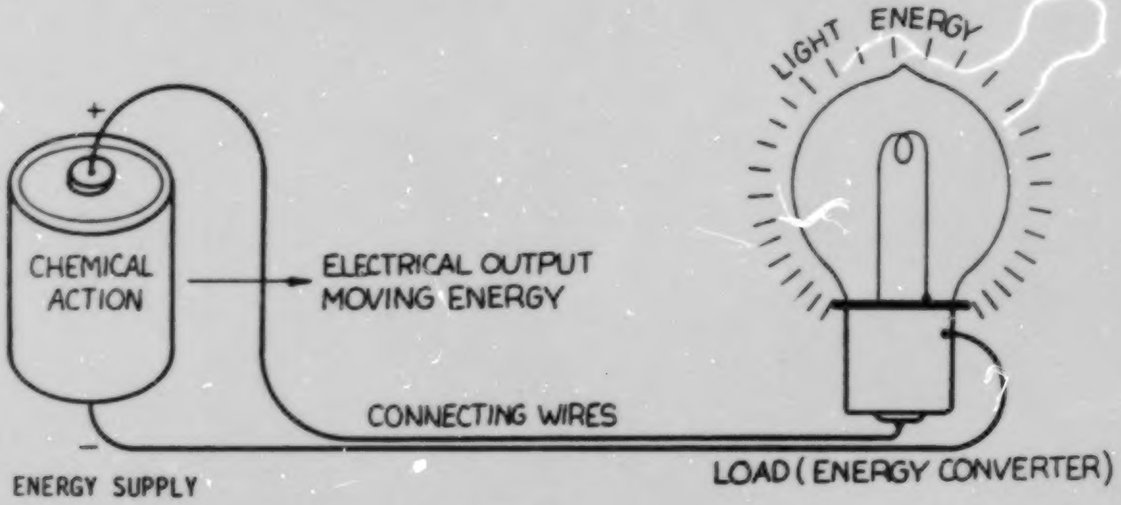
## Potential Energy

As was stated, potential energy is stored energy. The energy is there ready for us to use. This type of energy is not doing work until we use it to operate a device. The electrical outlets in your home provide energy in this manner as do batteries and other sources of electrical energy.

To be able to use potential energy, we must get it moving. This is done by converting potential energy to moving energy. When we connect a lamp to a battery, the potential energy becomes kinetic, or moving, energy which lights the lamp.

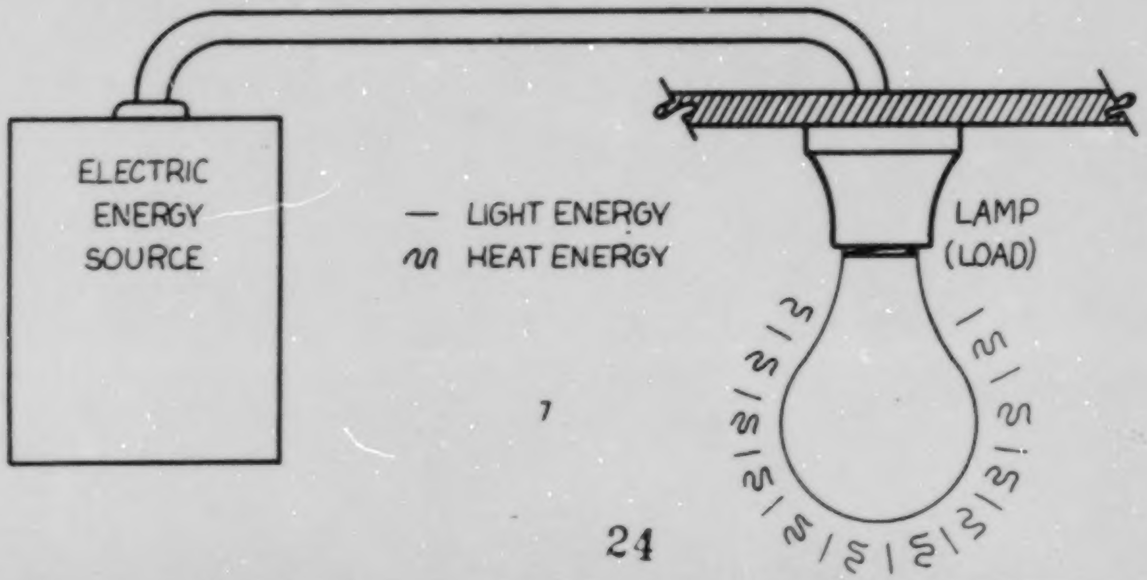
## Kinetic Energy

Shown below is an electrical circuit demonstrating how the chemical energy of the battery is converted to electrical energy. The electrical energy is moved to the lamp where it is converted to light energy. The lamp is an energy converter and is called the load in the circuit.


LIGHT ENERGY
+
CHEMICAL ACTION
ELECTRICAL OUTPUT MOVING ENERGY
CONNECTING WIRES
−
ENERGY SUPPLY
LOAD (ENERGY CONVERTER)

## Efficiency

With today's energy crisis, we are all concerned with conserving energy. Unfortunately, it is impossible to operate our machines with no loss. When we talk of efficiency, we are referring to how much energy we put into a machine, how much we were able to use, and how much was wasted in a form that we could not use. Let's take an example of a very common device that we all use. It is the common, screw-in, incandescent light bulb. Show below is a diagram of an incandescent lamp system.


ELECTRIC ENERGY SOURCE
— LIGHT ENERGY
ᔕ HEAT ENERGY
LAMP (LOAD)

In this type of system (which we all use), it is a fact that if 1,000 joules of energy were applied to the lamp, we would get only 200 joules of light. This means that the other 800 joules of energy went some place else. The energy that was not converted into light was converted into heat. The light bulb makes a better heater than a light source! To figure the efficiency of this lightbulb we use the following formula:

$$\text{percent efficiency} = \frac{\text{work out}}{\text{work in}} \times 100\ \%$$

Given: 1,000 joules electric input

200 joules light output

Find % efficiency

$$\text{Known } \%\ \text{eff} = \frac{\text{W out}}{\text{W in}} \times 100\ \%$$

$$\text{Solution: } \%\ \text{eff} = \frac{200}{1{,}000} \times 100\ \%$$

$$\%\ \text{eff} = .2 \times 100\ \%$$

$$\%\ \text{eff} = 20\ \%$$

Answer % eff = 20%

The other 80% of the energy in heat loss was wasted as an unwanted type of energy. All electrical devices do not operate as inefficiently as the light bulb. The fluorescent lamp is more efficient than the incandescent type. The power transformers that you see on the power poles operate with over 95% efficiency. Motors in clothes dryers, washers, etc., operate with from 50 to 70% levels of efficiency. By knowing the efficiency, we can make wise choices of electrical devices to save energy.

## Self-Test

1. Energy is

   (a) force.
   (b) pressure.
   (c) ability to do work.
   (d) travel.

2. The base unit for energy is the

   (a) joule.
   (b) meter.
   (c) newton.
   (d) neutron.

3. The symbol for work done in the joule is

   (a) P.
   (b) W.
   (c) Y.
   (d) A.

4. Efficiency is measured in the

   (a) newton.
   (b) meter.
   (c) percent.
   (d) joule.

5. Which device listed below has the lowest efficiency?

   (a) motor
   (b) washing machine
   (c) incandescent lamp
   (d) fluorescent lamp

6. The conversion of energy states that

   (a) energy can be created.
   (b) energy can be changed into another form.
   (c) energy can be destroyed.
   (d) energy is equal to the newton.

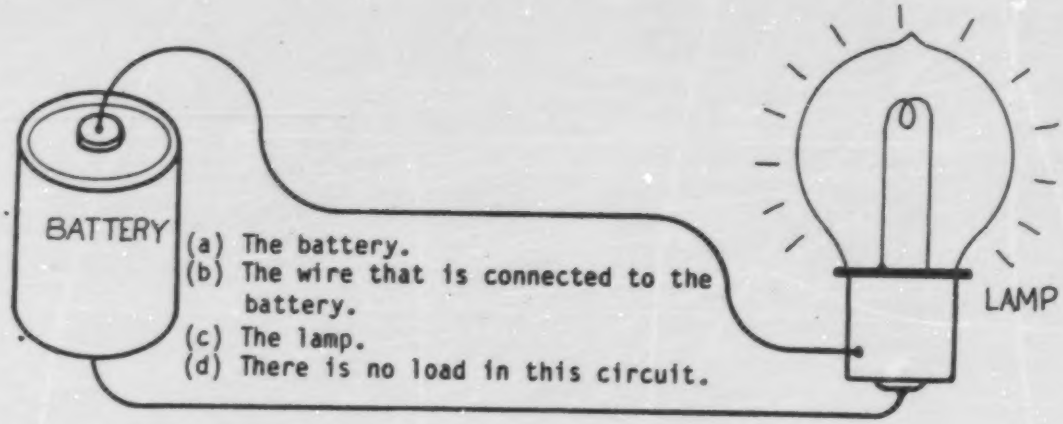
7. If you push on your car with a with a force of 450 newtons for 5 seconds but the car does not move,
   - (a) the work is equal to the pressure.
   - (b) no work is done.
   - (c) the work is equal to the newtons squared.
   - (d) 2,250 joules of work is done.

8. To calculate for the joule you must
   - (a) divide the newtons by the force.
   - (b) multiply the efficiency times the force.
   - (c) find the reciprocal of the number of newtons.
   - (d) multiply the distance times the force.

9. Efficiency of any device has to do with the
   - (a) amount of energy input compared to the wanted energy output.
   - (b) amount of heat dissipated.
   - (c) amount of energy input compared to the newtons applied.
   - (d) amount of time operated.

10. Stored energy is known as
    - (a) kinetic energy.
    - (b) newtons.
    - (c) potential energy.
    - (d) joules.

11. In the electric circuit that is shown below, what device is the load?



- (a) The battery.
- (b) The wire that is connected to the battery.
- (c) The lamp.
- (d) There is no load in this circuit.

# Task

Task Sheet

Solve the problems below:

1. How much work is done if we ride a bicycle 1 kilometer (1,000 meters) by applying 50 newtons of steady pressure to the pedals?

   __________ joules

2. How much work is done if you push a car 80 meters by pushing with a steady force of 820 newtons?

   __________ joules

3. Our flashlight batteries produce 240 joules of chemical energy to supply 200 joules of electrical energy to the flashlight lamp. What is the efficiency of the battery?

   __________%

4. Our refrigerator's ice maker was able to produce 10 pounds of ice. Each pound of ice represents 150 joules of energy. Our refrigerator used 1,950 joules of energy to produce the 10 pounds of ice. What is the efficiency of the refrigerator ice maker?

   __________%

5. The study lamp that I use gives 150 joules of energy in the form of light. To produce this we have to supply the lamp with 750 joules of electrical energy. What is the efficiency of the lamp?

   ______________%

# Answers

Answers to Task Sheet

1. 50,000 joules

   $W = F \times d$
   $W = 50 \times 1{,}000$
   $W = 50{,}000$ joules.

2. 65,600 joules

   $W = F \times d$
   $W = 820 \times 80$
   $W = 65{,}600$ joules.

3. 83.3%

   $$\%\ \text{eff} = \frac{W\ \text{out}}{W\ \text{in}} \times 100$$

   $$\%\ \text{eff} = \frac{200}{240} \times 100$$

   $$\%\ \text{eff} = \frac{5}{6} \times 100$$

   $$\%\ \text{eff} = \frac{500}{6} = 83.3\%$$

4. 76.9%

   $$\%\ \text{eff} = \frac{W\ \text{out}}{W\ \text{in}} \times 100$$

   $$\%\ \text{eff} = \frac{1{,}500}{1{,}950} \times 100$$

   $$\%\ \text{eff} = 76.9\%$$

Answers to Task Sheet

5. 20%

$$\% \text{ eff} = \frac{W \text{ out}}{W \text{ in}} \times 100$$

$$\% \text{ eff} = \frac{150}{750} \times 100$$

$$\% \text{ eff} = \frac{100}{5} = 20\%$$

# Final Test

1. If a lamp gives us 500 joules of light energy while it is being supplied with 1,200 joules of electrical energy, what is its efficiency?

   _____ %

2. How much work is done if you roll a rock 5 meters with a force of 1,000 newtons?

   _____ joules

3. How much work is done if you hold a 5 kilogram weight 1 meter from the floor for 10 minutes?

   _____ joules

4. Efficiency is measured in the

   (a) newton.
   (b) meter.
   (c) percent.
   (d) volt.

5. The symbol for work is

   (a) D.
   (b) A.
   (c) W.
   (d) P.

6. Efficiency is a factor of

   (a) the power used.
   (b) the amount of energy input compared to the energy output in the form wanted.
   (c) newtons times force.
   (d) the power used compared to the heat dissipated.

7. Moving energy is known as

   (a) DC voltage.
   (b) kinetic energy.
   (c) potential energy.
   (d) the joules per second.

8. The definition of energy is

(a) the force applied.
(b) the ability to do work.
(c) the pressure applied.
(d) the travel per time.

9. The base unit for energy is the

(a) work.
(b) newton.
(c) force per second.
(d) joule.

10. What type of lighting has the worst efficiency?

(a) fluorescent.
(b) phosphorescent.
(c) incandescent.
(d) iridescent.

11. The function of the load in an electric circuit is

(a) energy production.
(b) improving efficiency.
(c) energy conversion.
(d) no function.

# Final Evaluation

All answers on the Task Sheet must be 100% correct. Answers on the Final Test must be 90% correct.

| | OK | Re-Do |
|---|---|---|
| Task Sheet Score | | |
| Final Test Score | | |

When all checks indicate OK, proceed to the next learning package.

## SELF-TEST ANSWERS

1. c
2. a
3. b
4. c
5. c
6. b
7. b
8. d
9. a
10. c
11. c

# 2.2

## ATOMIC THEORY

### Goal:

The apprentice will be able to describe the atomic theory.

### Performance Indicators:

1. Describe parts of an atom.
2. Describe valence electrons.
3. Describe free electrons.
4. Describe insulators and conductors.

# BASIC ELECTRONICS

## Atomic Theory
## EL-BE-03

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| This learning package. | Draw the structure of the atom and name the parts which deal with electrical theory. |
| | Answer correctly questions pertaining to the structure of the atom. |

## Directions

Obtain the following:

This package.

## Learning Activities

_____ Read the Key Words list.

_____ Read the Information Sheets.

_____ Do the Self-Test.

_____ Do the Final Test.

_____ Do the Task.

_____ Obtain Final Evaluation.

## Key Words

Atom: The smallest bit of an element; the basic building block of matter.

Compound: Chemically united materials.

Electron: The negative bit of matter found in the atom in shells around the nucleus.

Matter: Anything that has weight and takes up space.

Mixture: Combination of materials that can be separated by mechanical means.

Nucleus: The center section of the atom which contains the positive charge.

Proton: The positive bit of matter in the atom found in the nucleus.

Valence: The system that has to do with the bonding of atoms together to form molecules.

## Information Sheet

In the last package we found that we need energy to do work. To do work was to apply pressure to make something move. When we use electricity to apply the pressure to make work take place, what is really happening? Where is the pressure coming from? What is moving? What kind of work is being done? Before we can answer these questions, we have to look into the electrical circuit, right into the materials of which it is made. The materials that are used in electrical circuits fall into three categories: conductors, semiconductors, and insulators.

The conductors include most metals. Copper is the most common one used. Conductors form the part of the circuit that allows the electricity to pass. The wiring in your house, the coils in motors and transformers, and all of the connecting cords to our televisions, lamps, etc., are all conductors.

The semiconductors are not as common. They are not good at allowing electricity to pass, but they do not stop it. Semiconductors are used in many types of electronic components. Two examples of components which use semiconductors are diodes and transistors.

The insulators are very important to electrical circuits. This type of material prevents the electricity from moving. The plastic covering on wires and the tape that we use to cover electrical connections are insulators. Our personal safety depends on the use of good insulators: they prevent us from being electrocuted.

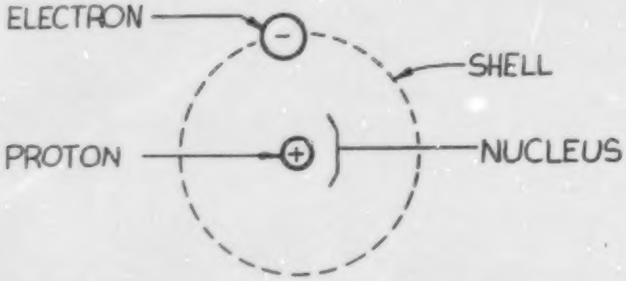
What is there about these materials that makes them act as they do in electrical circuits? To answer this, let us look into the materials themselves to see how they are put together.

Materials, no matter what kind, are called matter. Science tells us that matter is anything that has weight and takes up space. That covers everything from the air that we breathe to the ground that we stand on. Matter can be a gas, a liquid, or a solid. Matter can be metal or nonmetal. But whatever form or state of matter, laws apply as to how it is put together. Some materials are found as mixtures: they are made up of two or more things. Mixtures can be separated by mechanical means. Let's take the example of dirt in water. To remove the dirt, we can let the mixture settle and filter the dirt out of the water. In this way, we have separated a mixture by mechanical means.

Many materials are compounds. Like a mixture, a compound is made up of two or more things, but they have been combined by a chemical reaction. We cannot separate compounds by mechanical means. The water that we filtered is itself a compound. If we could look at water before its parts were combined chemically, we would see that it was really two very different kinds of materials. Two gases, hydrogen and oxygen, in the proper combination, make up water. Water is not a single material; we can break it down into two different materials. If we break water down to the point just before it separates into these two different materials, we would have the smallest bit of water possible. This amount of water would be so small that it could not be seen even with a powerful microscope. This amount would be called one "molecule" of water. A molecule of water is made up of two parts hydrogen and one part oxygen. $H_2O$ is the chemical formula for water. The $H_2$ stands for two atoms of hydrogen. The O stands for one atom of oxygen. When we write $H_2O$, we mean water. We also mean that a molecule of water is made up of two atoms of hydrogen united with one atom of oxygen.

Any material that can be reduced down to the atomic level (size) and still have identity as the same material is an element. Water cannot be broken down into the atomic level and still be water. When we break water down to atoms, we find two atoms of hydrogen and one atom of oxygen. Hydrogen can be broken down to the atomic level and is still hydrogen. Hydrogen, then, is an element. Examples of other elements are copper, gold, silver, and carbon. There are 92 natural elements. Materials that are made up of two or more elements are called compounds. Examples of compounds that are very important in electrical work are brass (made of copper and zinc) and glass (made up of silicon and carbon). Let us get back to the elements to find out how some of their atoms are put together.

One of the elements that make up water is hydrogen. Let's take a very close look at one atom of hydrogen. Always remember that the atom is so small that we have never seen it. The only way we know of its appearance is by experiment and calculation. Below is a diagram of a hydrogen atom. Note the name of each part.



Notice that it looks like a small solar system with a proton in the center and an electron in orbit around the outside. The center is called the nucleus. The orbit is called a shell. An atom of hydrogen is the simplest and lightest of all. Its atomic number is one. Before we go on to the next atom, let's review its parts.

## The Electron

This part of the atom is very light. It has the negative electric charge and is the part of the atom that is the most mobile. The electron is in motion around the nucleus in a sort of orbit or shell. Some atoms have many electrons and shells around the nucleus.

## The Proton

This part of the atom is heavier than the electron. In fact, it is over 1,800 times heavier than the electron. This part of the atom carries the positive electric charge and is locked up in the nucleus.

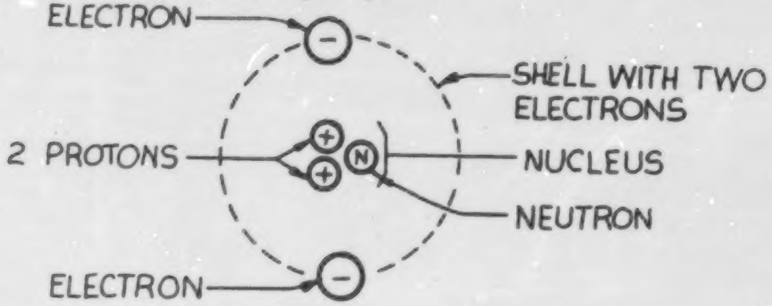
## The Nucleus

This is not a part as such. This is the name of the area in the center of the atom where the protons are grouped. In most cases the nucleus has more than just protons in it. It may contain neutrons. Remember that the nucleus is very dense and is responsible for almost all of the weight of the atom.

## The Neutron

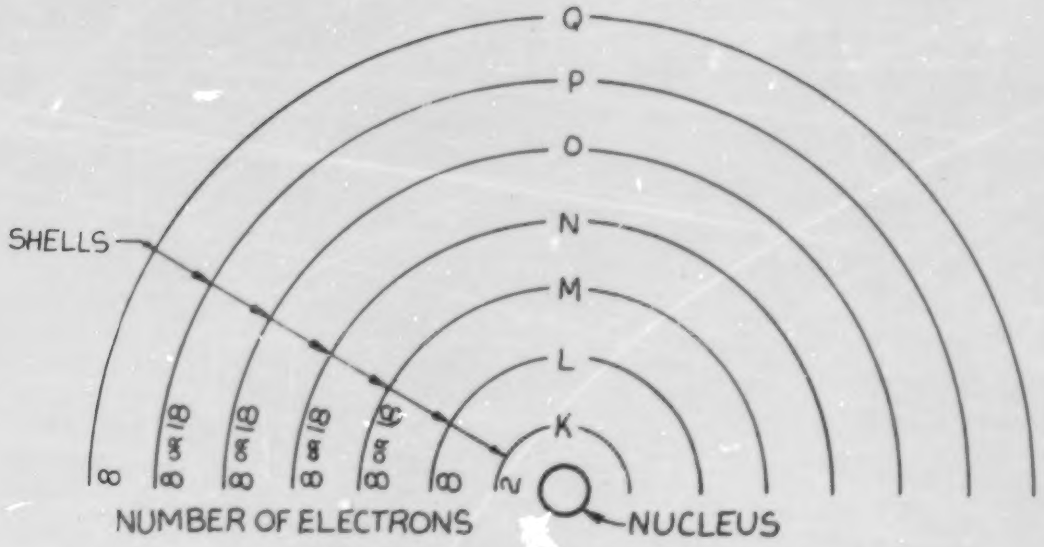
This particle is found in the nucleus and has no electrical charge. Electrically, we can ignore it.

Let's look at the next atom (atomic number two) in the atomic series. The name of this element is helium. Below is a diagram of an atom of helium. Study its parts. How does it differ from hydrogen?

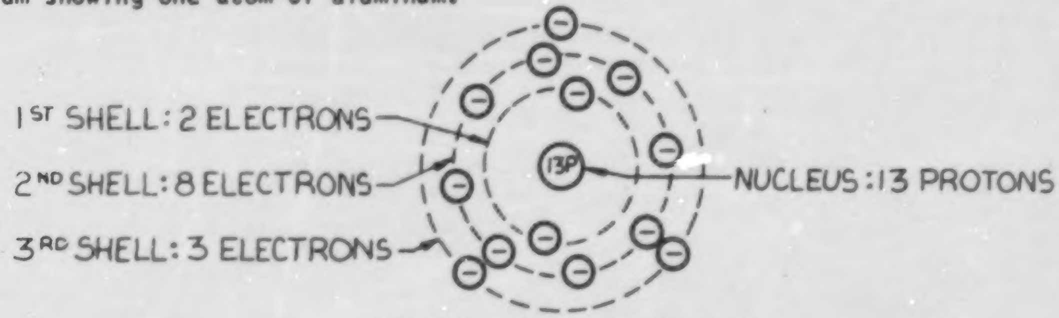


You will notice first that this atom is more complicated than hydrogen. It has two electrons and two protons while hydrogen and has one of each. This balance of electrons and protons is true for all atoms in the natural state: for each electron in the shells around the nucleus, there must be a proton in the nucleus. The difference between atoms of different materials is that they have more or less of these atomic parts: protons, electrons, and neutrons.

As we go up the atomic scale, the atoms become more and more complicated. Each time there are more electron-proton pairs, the atom gets larger. More shells are found around the nucleus. Each shell has a fixed number of electrons that can be in that shell in any specific element. On the following page is a chart showing the numbers of electrons that can be in each shell. This number of electrons is absolute only if followed by another shell. If the shell is an outer one, any number of electrons is possible up to the natural number for that shell.


Q
P
O
N
M
L
K
SHELLS
8
8 or 18
8 or 18
8 or 18
8 or 18
8
2
NUMBER OF ELECTRONS
NUCLEUS

As you can see from the above chart, there are seven shells for electrons. Depending on the material, all the shells may not be there and may not have a full complement of electrons. Let's look at a heavier material. Below is a diagram showing one atom of aluminum.


1ST SHELL: 2 ELECTRONS
2ND SHELL: 8 ELECTRONS
3RD SHELL: 3 ELECTRONS
13P
NUCLEUS: 13 PROTONS

ONE ATOM OF ALUMINUM

## Valence Electrons

The outside shell of electrons of the atom is the valence ring. The electrons in this group are the ones that interact with electrons of other atoms to hold atom to atom. This process is called bonding. Bonding can be very complicated. Remember that bonding takes place when chemical reactions take place. The trading of electrons from one atom to another occurs in this outer ring because the electrons are not held as tightly as they are in the inner shells. When atoms are bonded together, they form structures called molecules. Because the structure of the molecule varies a great deal, some of the valence electrons are not held to others in the bonding process. These unbonded electrons are called free electrons.

## Free Electrons

As stated above, free electrons can be caused by the bonding structure of the molecule. Any force from the outside can push the free electrons around in the material. The force can be almost any form of energy. A few examples are heat, light, magnetic energy, mechanical energy and chemical energy. In some materials, these valence electrons are locked into the bonding more tightly than in others. In these materials, it takes more outside energy to force the electrons around.

## Insulators and Conductors

Materials that have their electrons locked up in the bonding process will not let go of their electrons nor will they take any in. The only way that free electrons can become available in such materials is by the use of huge amounts of energy. This kind of material is called an insulator. Some of the common insulators include air, plastic, and glass. Insulators stop electricity. Because of this, we find insulators as covering on wires, sections of terminal strips, and any place we need protection from electricity.

A conductor is a material that has free electrons in the bonding system. It is very easy to produce electron movement in this type of material. Only small amounts of energy are needed to move electrons through conductors. Conductors are used as connecting links between electrical devices. Silver and gold are excellent conductors, but, because of their high cost, they are not the most frequently used. Copper is a very good conductor and is far less costly than gold or silver. Because of this, it is the most commonly used.

## Self-Test

1. The second shell of the atom can contain

   a. two electrons.
   b. eight electrons.
   c. any number of electrons.
   d. eight protons.

2. The part of the atom that has the negative charge is called

   a. the neutron.
   b. the nucleus.
   c. the first shell.
   d. the electron.

3. Matter is described as anything that has weight and

   a. is a mixture.
   b. takes up space.
   c. takes up valence.
   d. is an element.

4. The proton has the _____________ electric charge.

   a. neutral
   b. expanded
   c. positive
   d. negative

5. The nucleus is the center section of the atom which

   a. has the negative charge.
   b. contains only neutrons.
   c. is the lightest part of the atom.
   d. has the positive charge.

6. The valence shell of the atom

   a. is part of the atom where bonding takes place.
   b. is in the nucleus.
   c. has only positive charges.
   d. is always the second shell.

7. The number of electrons in any atom is equal to

   a. the number of protons.
   b. the number of protons and neutrons.
   c. the lowest energy level.
   d. two plus the number in the outer shell.

8. A mixture can be separated by

   a. chemical means.
   b. a double reaction.
   c. mechanical means.
   d. adding energy.

## Task

Draw the atom of aluminum and label all parts.

## Final Test

1. Mechanical means of separation will

   a. separate atoms.
   b. cause double reactions.
   c. separate a mixture.
   d. separate a compound.

2. The number of protons that are found in the nucleus is equal to
   a. the number of electrons in the shells around the nucleus.
   b. the number of shells.
   c. the number of neutrons.
   d. the number of electrons plus the number of neutrons.

3. The part of the atom that has to do with bonding is

   a. the positive charge.
   b. the neutron.
   c. always the second shell.
   d. the outer or valence shell.

4. The part of the atom that has the positive charge is

   a. the neutron.
   b. the proton in the nucleus.
   c. the electron in the nucleus.
   d. the lightest part of the atom.

5. The electron has the _______________ charge.

   a. neutral
   b. expanded
   c. positive
   d. negative

6. Science tells us that matter is composed of

   a. anything that has weight and takes up space.
   b. only elements.
   c. any mixture.
   d. anything that has valence.

7. The part of the atom that is the lightest is

   a. the proton.
   b. the electron.
   c. the outer shell.
   d. the neutron.

8. The second shell of the atom can have

   a. eight electrons.
   b. two electrons.
   c. any number of electrons.
   d. two protrons.

## Final Evaluation

All answers on Final Test and completed drawing on Task must be 100% correct.

| | | OK | Re-Do |
|---|---|---|---|
| Task Drawing | Proper number of protons, neutrons and electrons and proper labels | | |
| Final Test Score | Percent | | |

When all checks indicate OK, proceed to the next learning package.

## Answers

### Self-Test

1. b
2. d
3. b
4. c
5. d
6. a
7. a
8. c

INSTRUCTIONAL LEARNING SYSTEMS

# 2.3

## ELECTRICAL CONDUCTION

## Goal:

The apprentice will be able to describe how electricity is conducted.

## Performance Indicators:

1. Describe polarity.
2. Describe interaction of charges.
3. Describe ions.
4. Describe moving electrical charges.

# BASIC ELECTRONICS

## Electrical Conduction
## EL-BE-04

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| Examples of conductors and insulators. | Perform a test to determine which materials are conductors and which are insulators. |
| A test device. | Answer correctly questions pertaining to electrical conduction. |

## Directions

Obtain the following:

Materials to test.

A continuity tester.

## Learning Activities

______ Read the Key Words list.

______ Read the Information Sheet.

______ Do the Self-Test.

______ Do the Task.

______ Do the Final Test

______ Obtain the Final Evaluation.

## Key Words

Polarity: Having one of two opposite charges, one positive and one negative.

Ion: An atom which has an unbalanced charge.

Negative ion: An atom which has too many electrons and, therefore, has a negative charge.

Positive ion: An atom that has a shortage of electrons and, therefore, has a positive charge.

Repulsion: The action of pushing away.

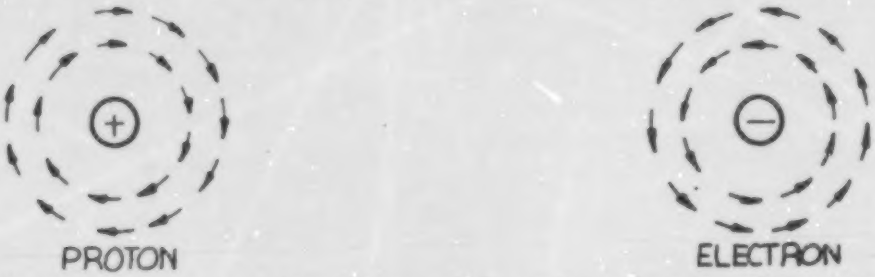
Continuity: An unbroken path for electron travel through a material.

# Information Sheet

Electricity is produced when electrons are freed from their atoms. Electrons in the outer orbit or valance ring have the highest energy level and are the farthest from the nucleus which has the positive charge.

## Polarity

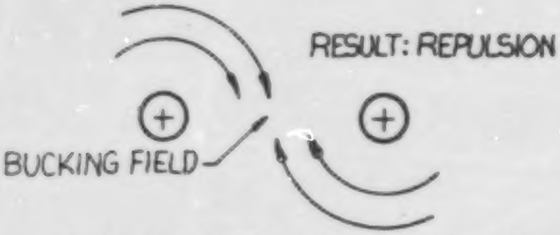
Our idea of electric charge or polarity comes from knowing how the electric fields are structured around the electron and proton. The exact nature of these fields is not known, but the action of these fields appears to be similar to magnetic fields. Below is a diagram of a proton and an electron showing the force field around each. (Each particle is shown round; the true shape is not known.)



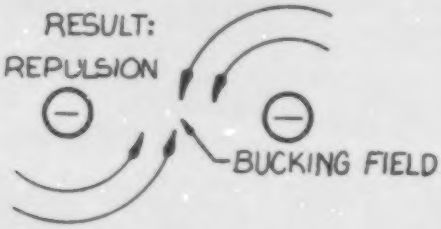
Notice the force field has direction. Also notice that the force fields are opposite in direction. In other words, the field surrounding the positive particle goes in one direction and the field surrounding the negative charge goes in the opposite direction.

## Interaction of Charges

Because of the direction of the fields there is a natural attraction or repulsion that takes place. (Repulsion is the opposite of attraction; it is a pushing away.) Study the diagram below which shows what happens when two positive charges are brought close to each other.



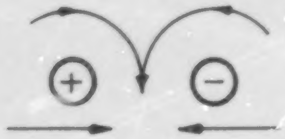
And below, you see what happens when two negative charges are brought together.



From these two examples we can see that when two positive charges are brought together, they repel each other; they push apart from one another. The very same action takes place when two negative charges are brought together.

From this we can say that LIKE CHARGES REPEL.

Let's check the last possible combination. What happens when a positive and a negative charge are brought together?



ATTRACTION

As you can see, the fields are now held together. They attract each other.

From this we can say that UNLIKE CHARGES ATTRACT.

This is the law of electrical charges. This action of attraction and repulsion makes it possible to move electrons by pushing them with other electrons (negative charges) or by pulling them with positive charges. This is the force behind the electric current. How can we build this force so that we can use it to do work? The answer is to unbalance nature by producing ions.

## Ions

As was stated before, in an atom there is a balance between electrons and protons. In a natural atom the number of electrons is the same as the number of protons. But this balance can be changed. By the application of energy, we can force electrons away from an atom. This will leave that atom with less electrons than protons. Then the atom will have more positive charges than negative charges. This charged atom is a POSITIVE ION. This positive ion will try to steal an electron from anywhere it can. It is natural for it to try to regain balance.

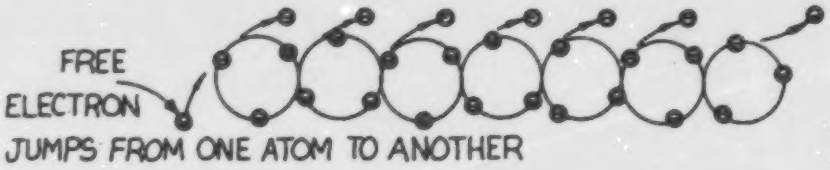
It is also possible to add an extra electron to the atom. Then there are more negative charges than positive charges. This charged atom is a NEGATIVE ION. This atom will try to give away an electron if it can to regain its balance.

## Producing Ions

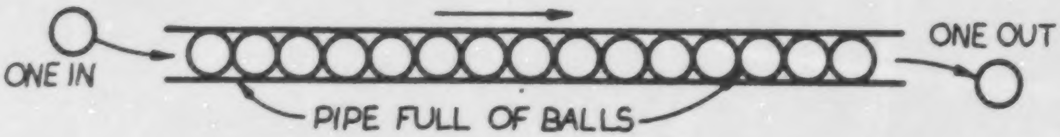
There are many ways that ions can be produced. A battery can produce ions with chemical action. Mechanical friction can also produce ions. If you shuffle your feet on a rug, you can pick up electrons. By picking up extra electrons, your body has negative ions on it. If you bring your finger near a door knob, or sometimes another person, the extra electrons will leave you with a spark, giving you a shock as the electrons move from you.

## Moving Electrical Charges

How can electrical charges move through things? As you shuffled on the rug, your shoes picked up the charge, but you lost the charge from your finger. The charge had to go from your shoe to your finger. How this happens is quite simple. You now have negative ions in your body. The charged atoms will try to regain their balance by getting rid of the extra electrons. Since the shoe is picking up more electrons, they must seek another place to leave the body. As your finger gets close to the door knob, zap!!, the electrons jump from one atom to another through your body from the shoe to the finger in a fraction of a second. To understand the process better, study the diagram below. In all of the atoms pictured, only the outer shell of each is shown because this is where the trading of electrons takes place.



The electron that goes in one end probably will not be the same one that leaves the string of atoms. Another way to picture this is shown below.



The pipe is full of balls. When you add a ball at one end, a ball comes out the other. In an electrical circuit, an action similar to this takes place at the speed of light, 186,000 miles per second, or by metric measure, 300,000,000 meters per second.

In some materials the electron movement occurs in a very limited way. These materials are called insulators. In materials with many free electrons the action occurs easily and these materials are called conductors. Because the conductive materials allow the exchange of electrons through them from one end to the other, it is said that they have continuity. In other words, a material with continuity provides a complete path for electron exchange.

In the following Task you will be asked to test materials and separate the insulators from the conductors. Remember that insulators prevent electricity from flowing because there are few or no free electrons in the bonding system. Conductors have many free electrons in the bonding system so do allow the flow of electricity.

## Self-Test

1. Insulators differ from conductors in that

   a. insulators have more protons.
   b. insulators have few free electrons.
   c. insulators are metals.
   d. insulators are bonded.

2. Materials with continuity

   a. are not conductive.
   b. allow electricity to pass through.
   c. are ferrous.
   d. are nonferrous.

3. An ion is

   a. a metal.
   b. an insulator.
   c. a charged atom.
   d. a lamp.

4. Like charges

   a. attract.
   b. have no force fields.
   c. repel.
   d. attract only metals.

5. Unlike charges

   a. attract.
   b. are only at the north pole.
   c. repel.
   d. are only in insulators.

6. Electricity travels at an effective speed of approximately

   a. the speed of sound.
   b. the speed of light.
   c. 300,000 meters per second.
   d. 120,000 feet per second.

7. A negative ion is

   a. an atom with an unbalance of neutrons.
   b. an electron.
   c. an atom that has more electrons than protons.
   d. an element.

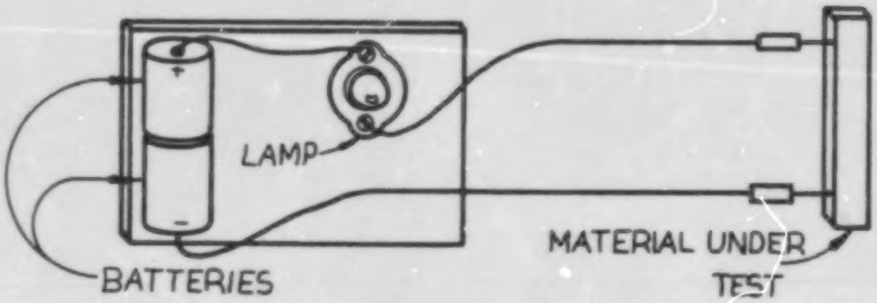
# Task

Materials:

Pieces of copper, brass, aluminum, iron, tin, lead, nichrome.
Pieces of string, wood, paper, rubber, plastic, cloth.

Equipment:

Test light unit or continuity tester as pictured below.



Procedure:

Test each piece of test material for conduction (continuity). To do this, touch one test wire to one end of the material under test and the other test wire to the other end.

Note the lamp. Does it light? If it lights, the material is a conductor. If it does not light, the material is an insulator.

List the materials under the proper column heading.

| CONDUCTORS | INSULATORS |
|---|---|

# Final Test

1. An atom that has an unbalance of electrons and protons is

    a. an ion.
    b. uncharged.
    c. an element.
    d. a compound.

2. The effective speed of electricity is

    a. the speed of sound.
    b. 300,000 meters per second.
    c. the speed of light.
    d. twice the speed of sound.

3. Unlike charges

    a. attract.
    b. have no action.
    c. repel each other.
    d. are unblanced.

4. Like charges

    a. attract.
    b. have no action.
    c. repel each other.
    d. are unbalanced.

5. An ion is

    a. an iron material.
    b. a lamp.
    c. an insulator.
    d. a charged atom.

6. A material that allows electron exchange all the way through is

    a. said to be an insulator.
    b. said to have continuity.
    c. said to have no ions.
    d. a nonmetal.

7. An insulator is

    a. a metal.
    b. a bonded metal.
    c. a material with few free electrons.
    d. a material with many free electrons.

# Final Evaluation

All answers on the Final Test and Task must be 100% correct.

| | OK | RE-DO |
|---|---|---|
| Task Score ______ % | | |
| Final Test Score ______ % | | |
| | | |

When all checks indicate OK, proceed to the next learning package.

## Answers
## Self-Test No. 1

1. b
2. b
3. c
4. c
5. a
6. b
7. c

INSTRUCTIONAL LEARNING SYSTEMS

# 2.4

## BASICS OF DIRECT CURRENT

### Goal:

The apprentice will be able to describe the basic characteristics of direct current.

### Performance Indicators:

1. Describe polarity.
2. Describe charge.
3. Describe voltage.
4. Describe current.
5. Describe resistance.
6. Describe wire sizes.

# BASIC ELECTRONICS

# Basics of Direct Current
## EL-BE-05

Test Draft
September 1981

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## Objectives

| Given: | The student will: |
|---|---|
| Information contained in this package. | Name and define the four factors of electricity. |
| | Describe what actions take place as values of voltage, current, and resistance are changed. |

## Directions

Complete this package.

## Learning Activities

_____ Read the Key Words List.

_____ Read the Information Sheets.

_____ Study the Task Sheets.

_____ Complete the Self-Test.

_____ Complete the Final Test.

_____ Obtain Final Evaluation.

## Key Words

Ampere: The base unit of measure of electron flow (one coulomb per second).

Charge: An electrical unbalance; the charge may be negative or positive.

Coulomb: The base unit of charge. 6.28 X $10^{18}$ electrons.

Current: The flow of electrons.

Ohm: The base unit of measure of resistance.

Polarity: Identification of charge; it may be + or -. Assignment of connections.

Power: The ability to do work.

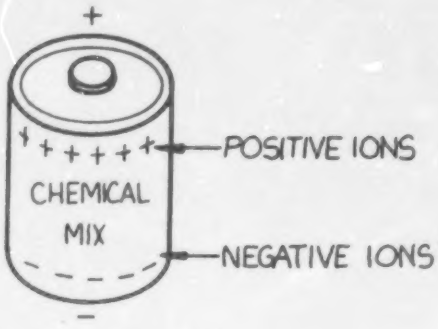
Resistance: The opposition to the flow of electrons.

Volt: The base unit of measure of electrical force.

Watt: The base unit of measure of electrical power.

# Information Sheet

As you learned in the last package, electrons can move through conductive materials. This movement occurs because the balance between the number of electrons and protons has been upset. The imbalance can be caused by energy applied to the material in some way or another. An example of a common device with an electron imbalance is a battery. Let's take a look at a flashlight battery. At one end is the positive pole, and at the other end, the negative pole. Inside there is a chemical mix which produces large amounts of negative ions (atoms with extra electrons) on the negative end, and positive ions (atoms with a shortage of electrons) on the positive end.



The action of the chemical mix takes place at a fixed speed. The result is that ions are produced at the same rate. When the battery was first constructed, this action took place to bring the battery to the 1.5 volt level. If the battery were to be used in a circuit which permits a very high current flow, the chemical action would not be able to maintain the surplus of electrons. The output voltage of the battery could drop below the 1.5 volt level. So we cannot use the electrical output from the battery faster than the imbalance is produced on the inside of the cell.

## Polarity

Polarity refers to the direction in which electrons flow or attempt to flow. The battery has a positive polarity on one end and a negative polarity on the other. This marking shows where the electrons are coming from and where they are going. How certain devices are connected in terms of polarity is extremely important. Diodes, capacitors, and transistors, meters and many other instruments must be connected to the power supply with their leads in the correct polarity. If these components or pieces of equipment were to be connected backwards (with the polarity reversed), they could be destroyed.

## Charge

As the negative ions are added to the negative end of the battery by the chemical action, a very interesting and important thing happens. Remember how electrons like each other? Right, they don't. They repel each other. The more electrons we pack on the negative end of the battery, the more pressure we get. The action is something like overpacking a suitcase. We keep putting more and more in until it is bulging and no more will fit. If the latch fails, the contents will pop out. The battery is like this. The electrons keep building on the negative side until they are so crowded that no more can fit. The electrons want to get to the positive end of the battery, but they cannot because the chemical action stops them one way, and the air stops them the other (air is a poor conductor). This imbalance we call charge. The amount of charge can be measured by knowing the number of electrons in the imbalance. This number is normally huge, and its unit of measure is the coulomb.

## Coulomb

The number of electrons measured as one coulomb is extremely large. The number is a quantity of electrons equal to 6,280,000,000,000,000,000. This is read six-thousand-two-hundred-eighty-quadrillion. To be able to use large numbers like this easily, a system called scientific notation is used. When this number is converted to scientific notation, it looks like this: $6.28 \times 10^{18}$. This stands for 6.28 multiplied by ten eighteen times. The advantage of this system is that it allows large numbers to be used without confusion. At this point don't worry about learning scientific notation but be able to recognize it when you see it.

## Joule per Coulomb

Now that we know that the coulomb is the base unit of electron charge, and we can remember that the joule is the base unit of energy, we can come up with a relationship to give us a measure of electrical force. This should be a measurable unit to show the amount of force between the negative and the positive polarity. This unit is called the volt.

## The Volt(V)

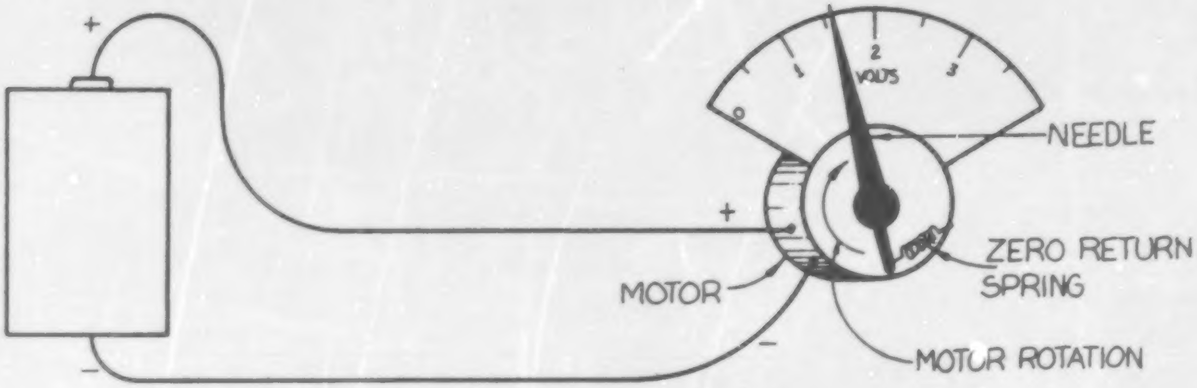
As shown above, the symbol for voltage is V. It is used to indicate the output of a battery or power supply. As an example, a flashlight battery is rated at 1.5 V.

The relationship between charge, energy and voltage is: voltage equals the energy divided by the charge.

$$\text{Voltage (V)} = \frac{\text{Energy W (Joules)}}{\text{Charge Q (Coulomb)}}$$

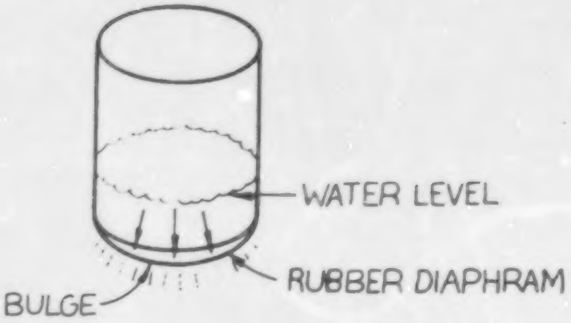
Just remember that voltage is the measure of the electrical push. The more voltage, the more push. The voltage is the prime mover of electrons.

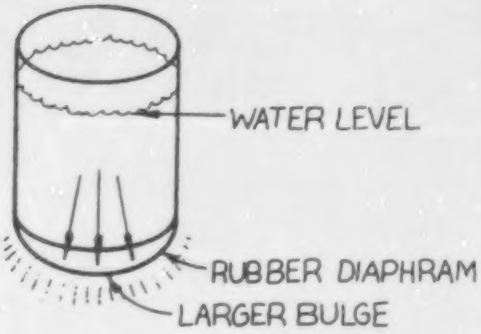
To measure voltage, we use a voltmeter. The voltmeter is like a small motor with a needle on the end of the shaft to show the amount of rotation of the shaft. Study the following drawing.



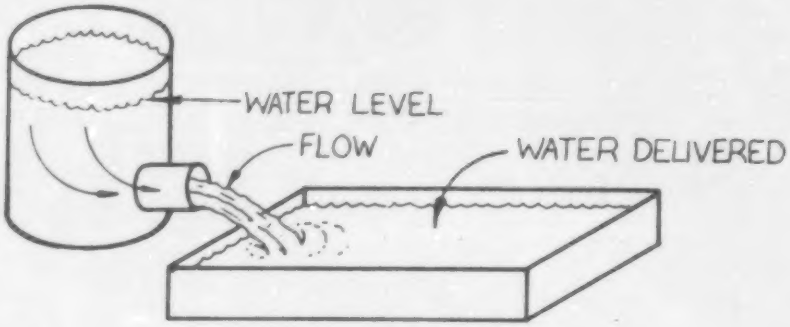
Notice that the more the needle goes upscale, the more force it takes to stretch out the zero-return spring. So the higher the voltage shown, the more force. It is important that the correct polarity be used when connecting the voltmeter. If it is connected in the reverse polarity, the needle will try to go downscale.

Another way to visualize what voltage means is to think in terms of water pressure. Study the diagram below.


WATER LEVEL
RUBBER DIAPHRAM
BULGE


WATER LEVEL
RUBBER DIAPHRAM
LARGER BULGE

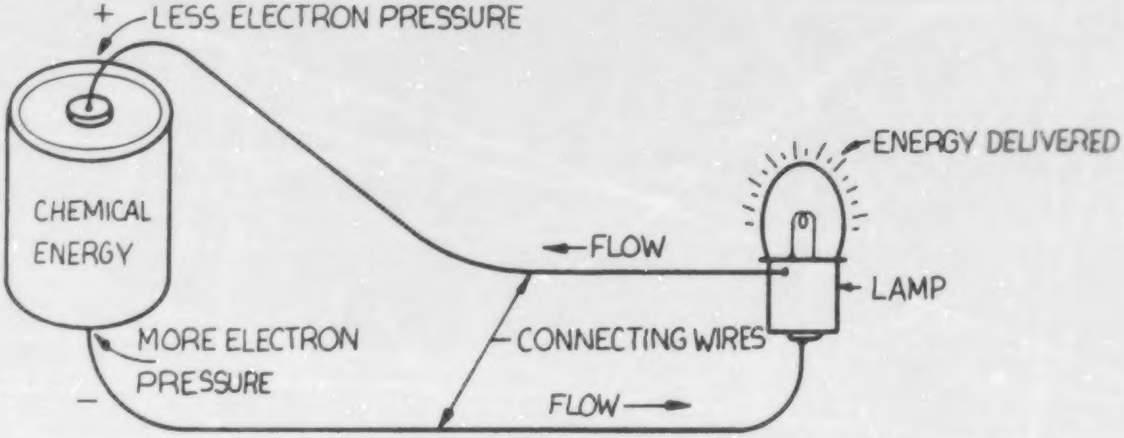
As you can see, the tank that has the most water in it has more pressure on the bottom. Let's go another step. If the tank had a hole in the bottom of it, the water would flow out.


WATER LEVEL
FLOW
WATER DELIVERED

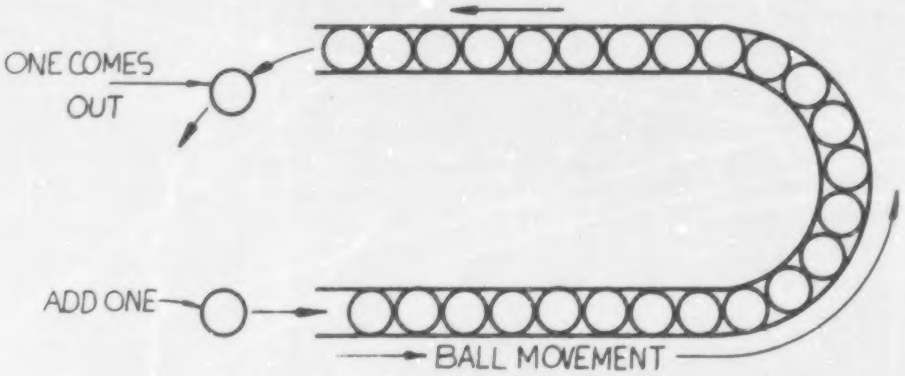
The flow would only take place if there were pressure on the bottom of the tank.

Current Symbol (I)

In an electrical circuit, flow also takes place. In the water system the material that was moving or flowing was water. In the electrical circuit the material that does the flowing is the electron. The electron flow or current will move from a place with more pressure to a place of less pressure. Study the circuit below.


+
LESS ELECTRON PRESSURE
CHEMICAL ENERGY
ENERGY DELIVERED
FLOW
LAMP
CONNECTING WIRES
MORE ELECTRON PRESSURE
−
FLOW

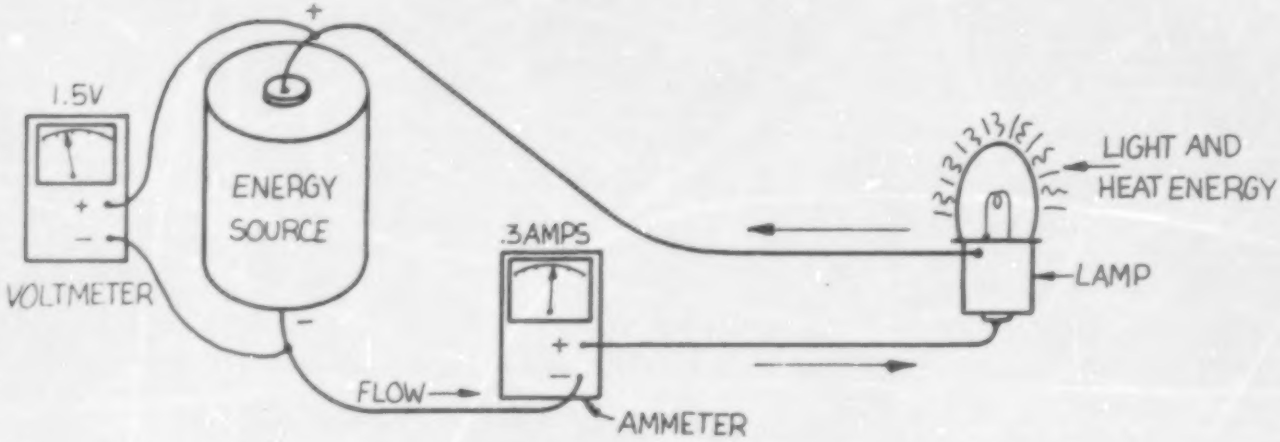
Notice that there is a complete path from the negative side of the battery through the connecting wires on through the lamp through more connecting wires and back to the positive end of the battery. This complete path must be connected all the way around the circuit or no current flow can take place. The current flow around the circuit is always an even trade. What this means is that for each electron leaving the negative end of the battery, there must be one going in on the positive end. The operation is something like a pipe filled with balls: when a ball is added to one end, one comes out the other. Study the following drawing.


ONE COMES OUT
ADD ONE
BALL MOVEMENT

The flow of electric current can be measured just as we can measure water flow in gallons per minute. The measure of electric current flow is the ampere.

## The Ampere (A)

To measure the flow of anything, all you have to do is to count how much is going by a given place in a given period of time. We know that in the electrical circuit the flow is made up of moving electrons. But in the electrical circuit it takes a huge amount of electrons per second to make very much happen. Remember the coulomb? Right, it was the huge amount of electrons that we use to measure charge. So we express the amount of current flow in the number of coulombs going by per second. You must realize that $6.28 \times 10^{18}$ electrons are a lot of electrons. One ampere, then, is equal to one coulomb passing one point in one second. To measure current flow in amperes we must put a coulomb counter in the circuit. To do this, the ammeter must be placed to check on all of the current flow. The ammeter is always connected in the circuit in series. Study the following circuit drawing.



Notice that the current must pass through the ammeter, on through the lamp, and back to the battery. The voltmeter is connected across the battery to check the battery's voltage when it is in operation. Let's take another look at the circuit. We know that the energy in the circuit comes from the stored energy in the battery. We also know that the energy that we are using takes the form of light and heat from the lamp. What is in the lamp that gives us the type of energy that we want? The answer is resistance.

## Resistance (R)

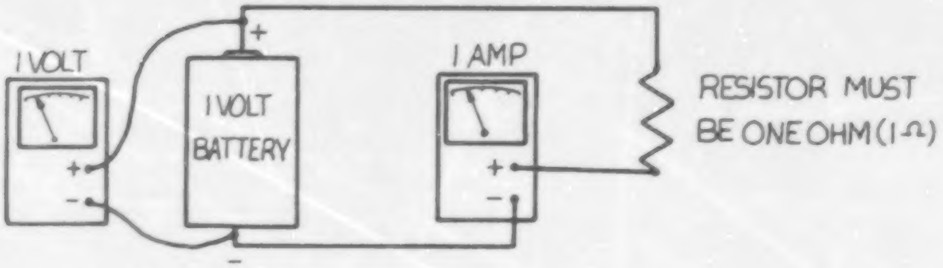
Inside the lamp there is a tiny wire which is made of tungsten. Tungsten is a metal which is electrically conductive but much less so than conductors like copper. The melting point of tungsten is so high that it takes white hot heat to melt it. When we force current through this tiny tungsten wire, the force from the battery gives up its energy in a sort of electrical friction. The result is high heat and light. It is the resistance that converts the energy into the form we want. Toasters, electric heaters, hair dryers, electric stoves and ovens are other examples of everyday devices which use resistance to convert electrical energy to heat and light.

There is a wide range of resistance levels in materials that we class as conductive. Iron has six times more resistance than copper. Silver is a better conductor than copper but not by much. Aluminum is not as good a conductor as copper but, because of its low cost and light weight, it is used by the power companies for power lines.

How do we measure resistance? What is the unit of measure for resistance? The ohm is the unit of measurement. Ω is the symbol for the ohm. To understand what an ohm is we can look at it in two ways.

## The Ohm (1)

From what you have read so far in this package you should know what a volt and an ampere are. If we hook up a circuit which has a battery with one volt output to a resistance that will allow one ampere of current to flow, that resistance, then, is one ohm. Study the circuit below.

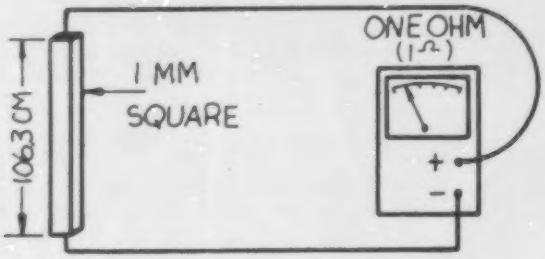


Notice that there is one ampere of current flow with one volt applied.

## The Ohm (2)

The other way to explain an ohm is to use a standard component that we know has one ohm of resistance.

A column of mercury 106.3 centimeters high and one millimeter square at a temperature of 0° Celsius has one ohm resistance end to end. Study the drawing below.



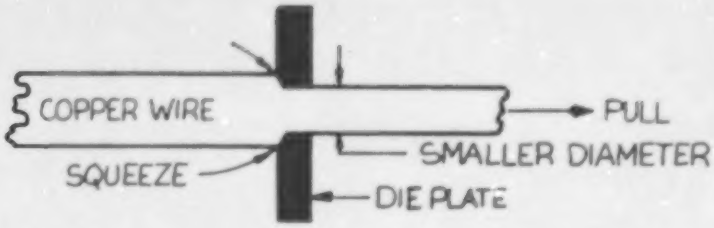
Take another look at that column of mercury. The resistance of the mercury or any other material depends on four factors:

1. The material of which it is made.
2. How long it is.
3. The cross-section area.
4. The temperature.

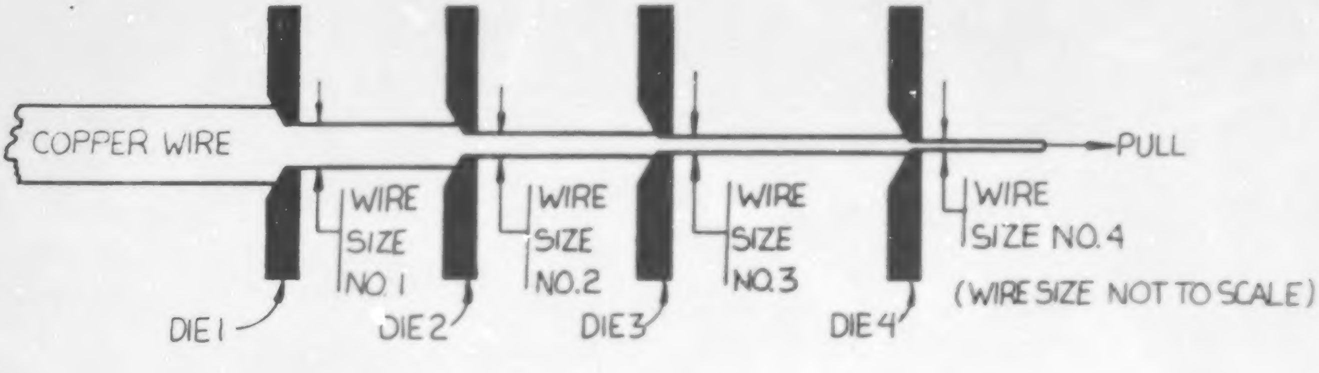
All of these four factors are important to review when circuits are designed to be sure that the connecting wires are of the right size. If the wire size is too small, they may heat and cause damage and energy loss.

## Wire Size

When wire is made, it is sized to a system of numbers for the diameter of the copper conductor. To understand how this system works we must understand how wire is made. Wire is drawn. To draw wire is to pull it through a hole which squeezes it into a smaller diameter and makes it longer. See the illustration below.


COPPER WIRE
PULL
SMALLER DIAMETER
SQUEEZE
DIE PLATE

The holes in the die plates must be in a size sequence decreasing gradually so that the copper will pull through rather than snap off. It is this sequence that gives us the wire size number system. In the illustration below there is a part of a wire drawing sequence showing four steps.


COPPER WIRE
PULL
WIRE SIZE NO. 1
WIRE SIZE NO. 2
WIRE SIZE NO. 3
WIRE SIZE NO. 4
(WIRE SIZE NOT TO SCALE)
DIE 1
DIE 2
DIE 3
DIE 4

When we select a given wire-size number, that number is the die number that the wire went through last. The dies are numbered in the order that the wire goes through them. This means that the hole in the #1 die is larger than the hole in the #2 die. Number one size wire, then, is larger than #2. As the wire size gets smaller, the numbers get larger. Number 0 wire is almost as large as a pencil, whereas, number 36 wire is as fine as hair.

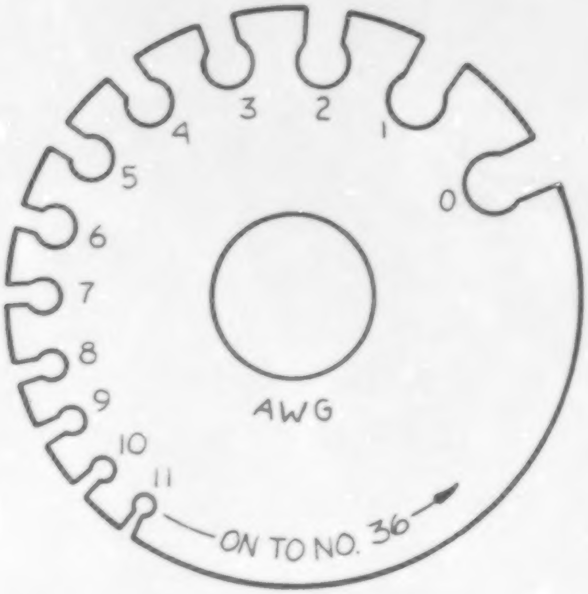
The amount of current (amps) that a given wire size can carry without heating varies somewhat, but here is a chart with some examples of wire size and current capacity. (Copper wire.)

# 6--50 amps
# 8--40 amps
#10--30 amps
#12--20 amps
#14--15 amps

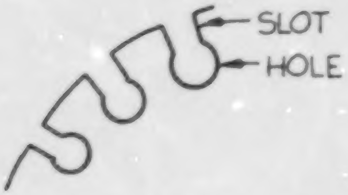
In most cases copper wire comes in even number sizes. The smaller the size of the wire, the less current it can carry.

Measuring Wire Size with a Wire Gauge.

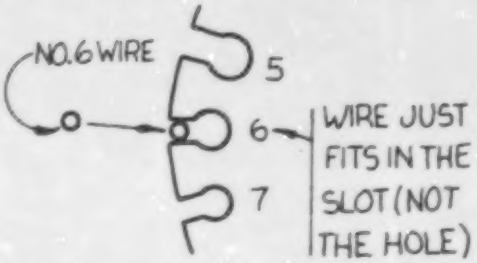
The wire size can be determined by the use of a wire gauge. The name of the wire gauge that is in general use is the American Wire Gauge (AWG). The drawing below shows the AWG. The sizes shown start at #0 and go to #11, but the gauge continues to #36.



Notice the shape of the cutouts around the gauge.



The cutout is made up of a slot cut into a hole. To properly use the wire gauge the bare round wire is tried into the slots until one is found that the wire just fits. The hole is not used for wire measurement.



## Power and Energy

An electrical circuit is a system of transporting power from one place to another. On the input end we have a source of energy which is converted into electricity. The battery does this. The chemical energy produces the electrical imbalance. Wires are connected to the battery which lead to the load end of the circuit. The load converts the electrial energy into the form that we want. The loads can take many different forms. A light bulb gives us light. An electric heater gives us heat. The electric motor gives us motion. How can we measure just how much electrical power we are using in a device? Power is explained as how fast energy is used to do work. The base unit for energy is the joule and the base unit of time is the second. Power, then, can be measured in the joule per second. The name given to this joule per second measure is the watt. So the base unit of electrical power is the watt. The symbol used is W for watts and P for power.

## Self-Test

1. Polarity is identified by

   a. numbers.
   b. color code.
   c. the shape of terminal or markings of + or -.
   d. the method of connection.

2. The ion producer in the battery is

   a. a coil of wire.
   b. aluminum foil.
   c. a chemical mix.
   d. a tungsten electrode.

3. The voltage level from one flashlight battery is

   a. 2.5 volts.
   b. 3 volts.
   c. 1 volt.
   d. 1.5 volts.

4. The quantity of electrons that equals one coulomb is

   a. 1.414 X 10.
   b. 3.14 X $10^{18}$.
   c. 6.28 X $10^{18}$.
   d. one billion.

5. One ampere of current is equal to _________ passing one point.

   a. one joule per second
   b. one volt per coulomb
   c. one ohm per volt
   d. one coulomb per second

6. The electrical factor of voltage is explained as

   a. the flow of electrons.
   b. the resistance to electron flow.
   c. the force or pressure.
   d. the power squared.

7. If the voltmeter is connected in reverse,

    a. no damage will result.
    b. the reading must be inverted to be correct.
    c. the meter pointer will go down off-scale.
    d. the reading will be in ohms.

8. The symbol for current is
    a. A
    b. R
    c. P
    d. I

9. The four factors that determine resistance are

    a. ____________________
    b. ____________________
    c. ____________________
    d. ____________________

10. In the wire-size number system

    a. the larger the diameter of the wire, the smaller the number.
    b. the smaller the wire diameter, the smaller the number.
    c. the smaller the number, the longer the wire.
    d. the larger the wire diameter, the larger the number.

11. The ohm is the unit of measure of

    a. power.
    b. amperes.
    c. battery voltage.
    d. resistance.

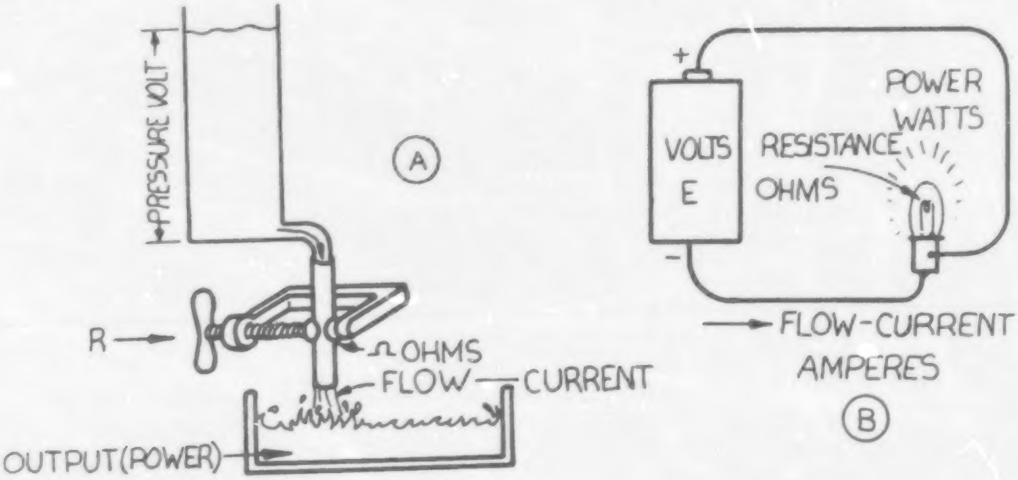
12. The unit of measure of electric power is the

    a. ohm.
    b. watt.
    c. coulomb.
    d. ampere.

# Task

## The Complete Circuit

The following analogy and circuits are provided for your study. Look at each drawing then read the conclusions. Do you agree with them? If you don't or are confused, re-read the information sheets and try again.


PRESSURE VOLT
Ⓐ
R
Ω OHMS
FLOW
CURRENT
OUTPUT(POWER)
+
−
VOLTS
E
POWER
WATTS
RESISTANCE
OHMS
FLOW-CURRENT
AMPERES
Ⓑ

1. If the voltage (pressure) were increased and the resistance stayed the same, the flow would increase.
2. The resistance restricts the flow.
3. If the resistance were decreased, the flow would increase.
4. An electric lamp is a resistive unit.
5. If the voltage were reduced, the flow would decrease.
6. If the voltage were increased, the power output would increase.
7. If the flow decreased and the voltage stayed the same, the resistance would increase.

Complete the chart below. (Fill in the missing arrows.)

This means that the value has increased.

This means that the value has decreased.

This means that the value has stayed the same.

Example:

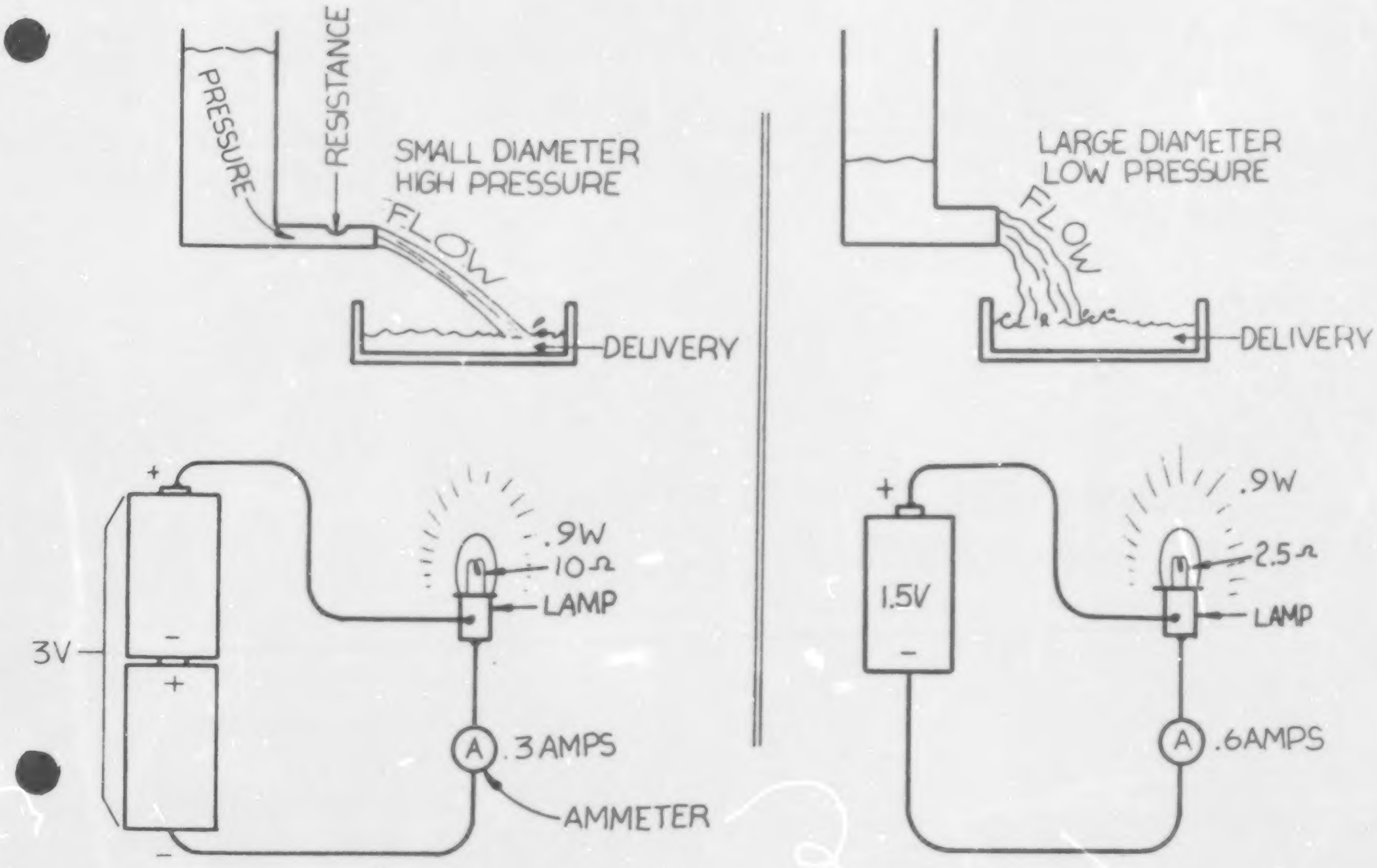
| | Voltage | Current | Resistance |
|---|---|---|---|
| 1. | ↑ | → | ○—(↑) |

In this case, if the pressure (voltage) increased and the current stayed the same, the resistance must have increased to keep the current the same.

Below is the rest of the chart. Some of the problems are done for you. Check them over, then complete the chart.

| | Voltage | Current | Resistance |
|---|---|---|---|
| 2. | → | ↑ | ↓ |
| 3. | ↓ | → | ↓ |
| 4. | ○ | ↑ | → |
| 5. | → | ↓ | ○ |
| 6. | → | ○ | ↑ |

Answers: 4 ↑ 5. ↑ 6. ↓


PRESSURE
RESISTANCE
SMALL DIAMETER
HIGH PRESSURE
FLOW
DELIVERY
LARGE DIAMETER
LOW PRESSURE
FLOW
DELIVERY
+
3V
–
+
–
.9W
10Ω
LAMP
A
.3AMPS
AMMETER
+
1.5V
–
.9W
2.5Ω
LAMP
A
.6AMPS

1. Both circuits in A and B have the same energy output (power output).
2. The circuit in B will operate only half as long as circuit A will. Energy reserve in circuit A is twice that of circuit B.
3. Circuit A has more energy reserve than circuit B.
4. There is less resistance in circuit B than in circuit A.
5. There is more current flow in circuit B than in circuit A.
6. The applied voltage is higher in circuit A than in circuit B.
7. The amount of current flow increases as the resistance increases.
8. The current flow increases as the resistance decreases.

# Final Test

1. Polarity is represented by

   a. the method of connection.
   b. the shape of terminal or markings of + or -.
   c. color code.
   d. numbers.

2. The ion producer of a battery is

   a. a coil of wire.
   b. a liquid.
   c. a tungsten electrode.
   d. a chemical mix.

3. Voltage of a flashlight battery is

   a. 3 volts.
   b. 1 volt.
   c. 1.5 volts.
   d. 2.5 volts.

4. The amount of electrons that equals one coulomb is

   a. one billion.
   b. 6.28 X 10.
   c. 6.28 X $10^{18}$.
   d. 3.14 X $10^{18}$.

5. One ampere of current is equal to ____________ passing one point.

   a. one ohm per volt
   b. one coulomb per second
   c. one joule per second
   d. one volt per coulomb

6. Electrical factor of voltage is explained as

   a. the flow of electrons.
   b. the resistance to electron flow.
   c. the force or pressure.
   d. the power squared.

7. If the voltmeter is connected in reverse,

   a. the reading will be in ohms.
   b. the meter pointer will go down off-scale.
   c. the reading must be inverted to be correct.
   d. no damage will result.

8. A symbol for current is

   a. I
   b. R
   c. P
   d. H

9. The four factors that determine resistance are

   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________

10. In the wire-size numbering system

    a. the larger the wire diameter, the larger the number.
    b. the smaller the number, the longer the wire.
    c. the smaller the wire diameter, the smaller the number.
    d. the larger the diameter of the wire, the smaller the number.

11. The unit of measure of electric power is the

    a. watt.
    b. ampere.
    c. ohm.
    d. coulomb.

12. The ohm is the unit of measure of

    a. battery voltage.
    b. resistance.
    c. amperes.
    d. power.

# Final Evaluation

The Final Test score must be 90% or better.

| | OK | Re-Do |
|---|---|---|
| Task Sheet Score | ______ | ______ |
| Final Test Score | ______ | ______ |

When all checks indicate OK, proceed to the next learning package.

# Answers

## Answers to the Self-Test

1. c
2. c
3. d
4. c
5. d
6. c
7. c
8. d
9. (in any order) material, temperature, length, cross-section area.
10. a
11. d
12. b

INSTRUCTIONAL LEARNING SYSTEMS

# 2.5

## INTRODUCTION TO CIRCUITS

| **Goal:** | **Performance Indicators:** |
|---|---|
| The apprentice will be able to read circuit drawings and diagrams. | 1. Read schematic diagrams of electrical circuits.<br>2. Read pictorial diagrams of electrical circuits.<br>3. Read diagrams of parallel circuits.<br>4. Read diagrams of series circuits. |

# BASIC ELECTRONICS

# Introduction to Circuits
## EL-BE-11

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| Schematic or circuit diagrams of series and parallel circuits | Connect the components together according to the diagram. |
| A series circuit with a missing or disconnected wire | Determine whether or not the current is lost in each of the components. |
| A parallel circuit where one component has been removed | Determine whether or not the current is lost in each of the other components. |
| Four questions on circuits | Answer each question correctly. |

## Directions

Obtain the following:

| | |
|---|---|
| 1 each | 82 ohm, 1/2 watt resistor |
| 2 each | Type #680 pilot lamp (or equivalent) |
| 1 each | DC Voltage Source 5V or 0-15V minimum adjustable |
| | Interconnecting wires or leads |

## Learning Activities

______ Study Key Words list.

______ Read Information Sheets.

______ Do the Self-Test.

______ Do Tasks.

______ Do the Final Test.

______ Obtain Final Evaluation.

## Key Words

Circuit: A group of electrical components and interconnections arranged to perform some useful function.

Circuit diagram: The same as a schematic diagram. (See below.)

Electrical components: The parts of devices that make up electrical circuits.

Parallel connection: Two or more components connected together such that each component is connected between or across the same two points in the circuit.

Pictorial diagram: A drawing of how electrical components are interconnected showing actual pictures or sketches of the components in the correct locations for assembly.

Series connection: Two or more components connected end to end so that only one end of any component connects to any other component.

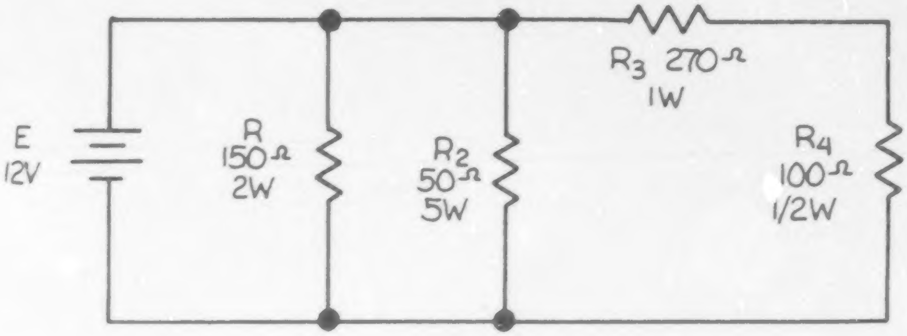
Schematic diagram (schematic): A drawing of how electrical components are interconnected using symbols to represent the components.

Voltage drop: The voltage across an electrical component (other than a source) caused by a current flowing in it.

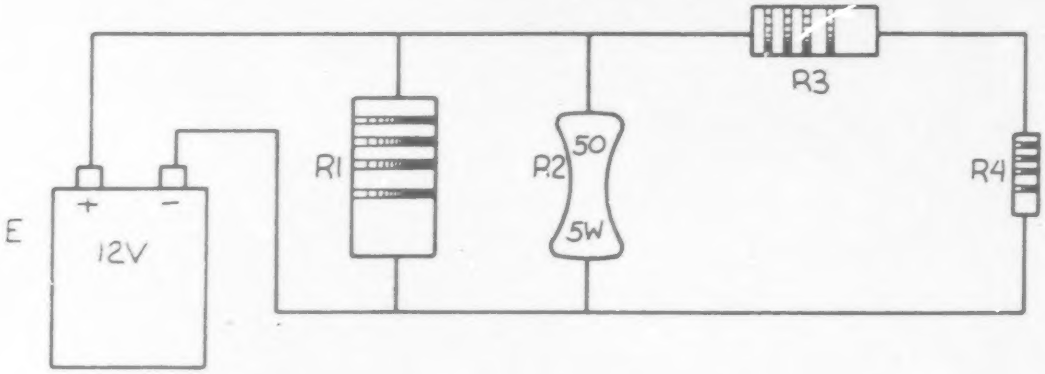
## Information Sheet

You should now have enough information on voltage sources and resistors to connect them together and make a complete circuit. Before you get too involved, however, you should learn some names for the types of circuits you will see and how they will be drawn on paper.

A schematic diagram or schematic, for short, is a drawing of electrical components and their interconnections to form a circuit. Symbols are used for the components, and lines are used for the interconnecting wires. A schematic may also be called a circuit diagram. A pictorial diagram is a drawing containing actual sketches of the components instead of symbols. These diagrams are used by assembly people to construct electronic equipment. They show every detail in the construction including position and location of components and interconnecting wires.



Schematic or Circuit Diagram



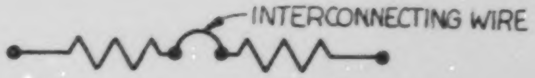
Pictorial Diagram

A schematic or circuit diagram is used by technicians and engineers to see how the components are interconnected. The schematic gives enough information to allow the experienced person to calculate currents and voltages that will be measured when the complete circuit is energized. In the circuits you will be constructing, the details of a pictorial diagram will not be important and only schematics or circuit diagrams will be used.

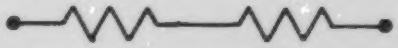
There are two different ways to interconnect two components, series or parallel. If only one end of each component is connected together, they are connected in series. The interconnecting wire is usually not drawn so that the ends are just shown touching each other.

Schematic or Circuit Diagram

of Two Series Resistors

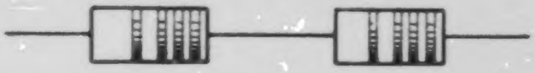


or



Pictorial Diagram of Two

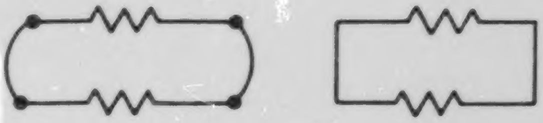
Series Resistors



If the components are connected between or across the same two points, they are in parallel.

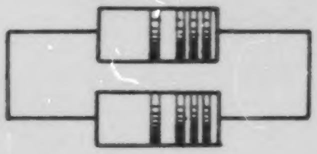
Schematic or Circuit Diagram

of Two Parallel Resistors



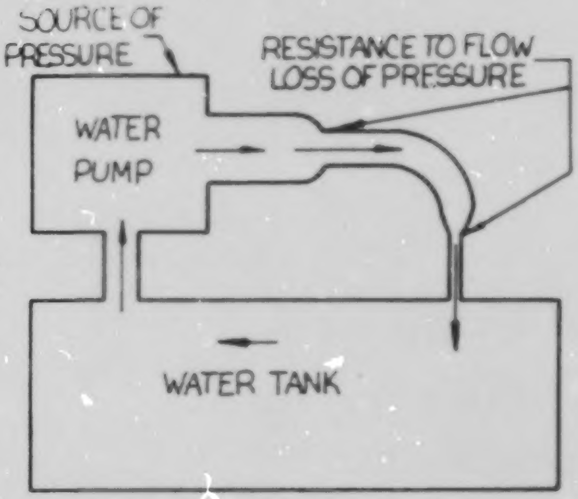
Pictorial Diagram of Two

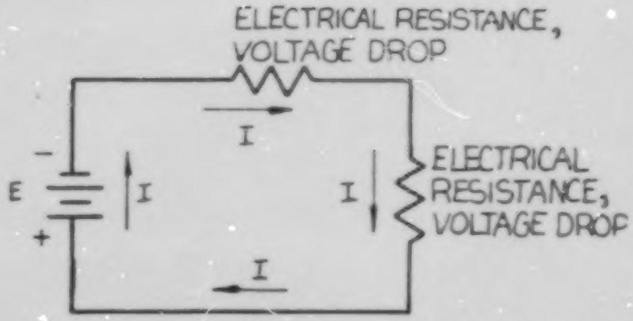
Parallel Resistors



In order to power the circuit, a voltage source must be added. This will cause current to flow. In a series circuit the voltage source is connected end to end as the resistors are. The series circuit can have many more components, but they will all be connected end to end in the same way.

In the package called Basics of Direct Current, you were introduced to an analogy between electrical current and water flow through a pipe. The same analogy should be helpful to you in understanding the ideas of current flow and voltage drops in simple series and parallel circuits. A water flow analogy of a series circuit is given first.




ELECTRICAL RESISTANCE, VOLTAGE DROP
ELECTRICAL RESISTANCE, VOLTAGE DROP
E
−
+
I
I
I
I

I is electrical current.
E is source of voltage.

The water pump is the source of water pressure and represents the source of voltage. The flow rate (amount of water flowing per second) represents the electrical current. The narrowing of the pipe resists the flow of water and represents electrical resistance.

In the water system for a given pump pressure, the more resistance that there is to the flow of water, the less the flow rate will be.

Likewise in the electrical circuit, the more resistance in the circuit, the less will be the current for a given voltage of the source.

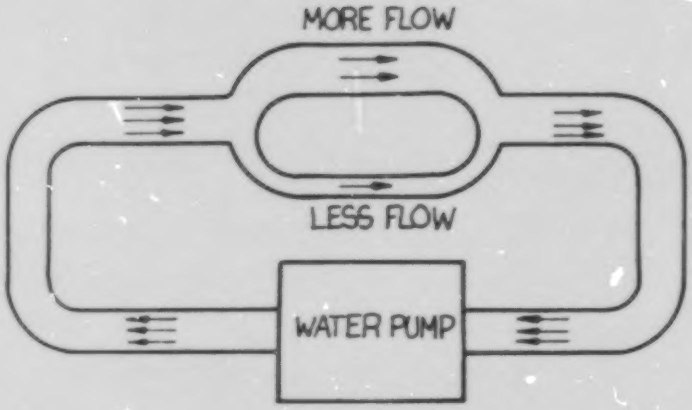
In the water system, the water is flowing at the same flow rate anywhere in the system. If it is two gallons per second coming from the pump, then it is two gallons per second anywhere in the pipe or in the return path through the water tank.

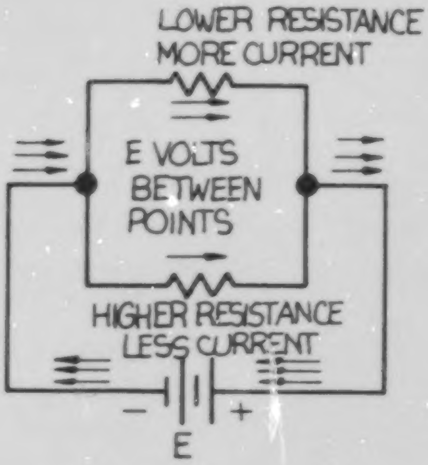
In the electrical circuit, the current is the same everywhere in the circuit. If it is one ampere out of the voltage source, it will be one ampere in each resistance and in all the interconnecting wires. Remember that one ampere is one coulomb per second which also equals 6,280,000,000 billion electrons per second.

The water pressure is less in the narrower pipes. In the narrower pipes a lesser amount of water has to flow at a greater speed to maintain the same flow rate.

The voltage is less after passing each resistor in the electrical circuit. The current or rate of electron flow or the coulombs per second stays the same. Just as there is a loss of pressure at each narrowing of the pipe, there is a voltage loss across each resistor in the electrical circuit.

In a parallel electrical circuit the voltage source is connected in parallel, that is, across the same two points. A water flow analogy of a parallel circuit is given next.





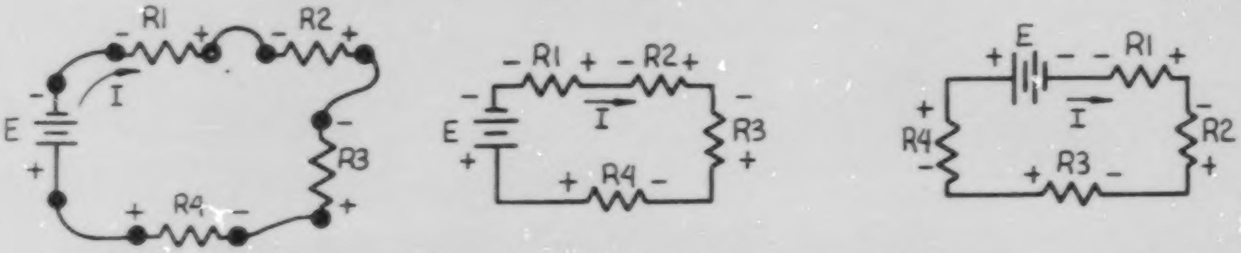
Notice that, just as the water divides into separate paths in the water pipes, the electrical current divides into separate paths in the parallel resistors.

The amount of water in each of the separate paths adds up to the total water entering or leaving. Less water flows into the narrower pipe; it has more resistance to the flow. Likewise the electrical current in each of the parallel resistors adds up to the total current entering or leaving the parallel circuit. Less current flows in the path with the largest resistance. Since each resistor is connected between the same two points, the voltage is the same across each resistor. The voltage source is also connected between those two points, so the resistors and the source all have the voltage of the source across them.

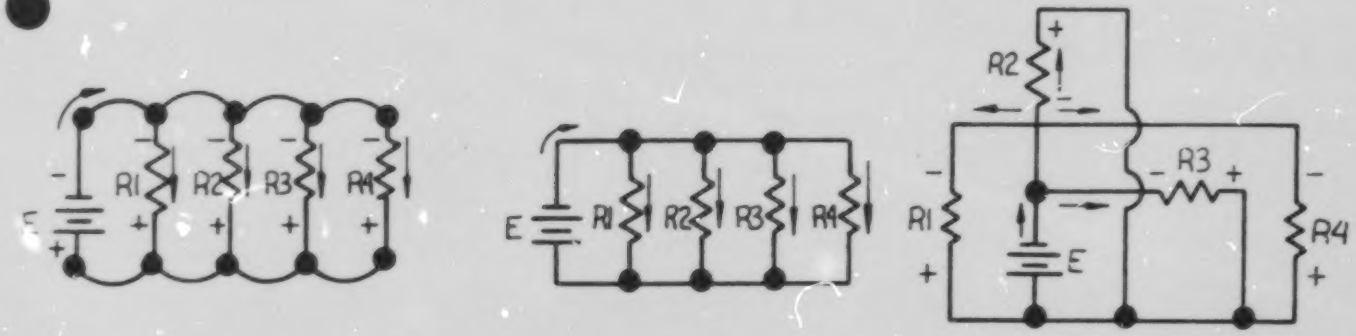
A series circuit or a parallel circuit may be drawn in different ways on a schematic or circuit diagram but still be the same circuit. The following circuit diagrams of different ways of drawing the same series circuit and different ways of drawing the same parallel circuit show this.

Notice that the direction of each current is determined by the polarity of the source.

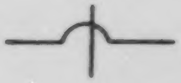
Notice that the end of the resistor where the current enters always has a negative polarity with respect to the other end.



Different Ways to Draw the Same Series Circuit

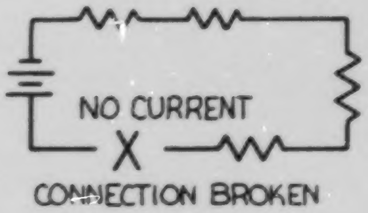


Different Ways to Draw the Same Parallel Circuit

 indicates where wires cross but do not touch (are not attached)

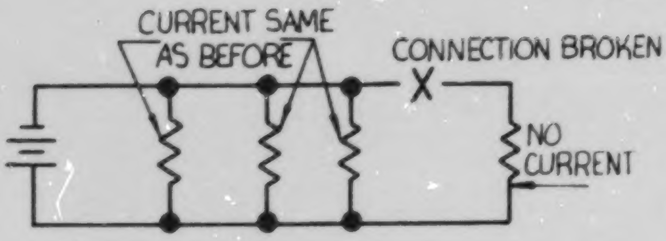
The dots indicate locations where the current can divide or separate into the different paths and are usually shown only when more than two connections are made at the same place.

Later on you will learn that you can make other circuits that are combinations of series and parallel circuits. These more complicated circuits will not be explained now. In a series circuit if only one interconnecting wire is broken or removed, the current will go to zero in all of the components in the circuit. An example of this is a series string of Christmas tree lights. If one light burns out, all of the lights will go out. This is because, when a light burns out, the electrical path through all the lights is broken. This is like a water pipe that is plugged up so that water cannot pass through. The flow will stop throughout the pipe. In a series electrical circuit when a wire is broken or removed, the electron flow or current is interrupted and current is stopped everywhere in the circuit.



SERIES CIRCUIT

In a parallel circuit, however, if one of the components other than the source is opened or removed, the same current will still flow in the others. The total current coming from the source will change, however. An example of this is a parallel string of Christmas tree lights. If one light burns out, the others will remain lighted. Another example is your household wiring. Each outlet is in parallel, and when a light burns out in your house, the others stay lighted.


CURRENT SAME AS BEFORE
CONNECTION BROKEN
X
NO CURRENT

PARALLEL CIRCUIT

Using the water analogy, if one pipe in a parallel branch of pipes is plugged, the other pipes will still carry the same water flow. The total flow will be less, however.

## Self-Test

1. A circuit drawing that uses symbols to represent electrical components is called a

   a. pictorial diagram.
   b. schematic drawing.
   c. resistor drawing.
   d. photograph.

2. Components in series have the same

   a. current.
   b. color.
   c. voltage.
   d. size.

3. Components in parallel have the same

   a. current.
   b. color.
   c. voltage.
   d. size.

4. In a series circuit, if a connection is broken, the current in each component

   a. increases.
   b. stays the same.
   c. is different.
   d. goes to zero.

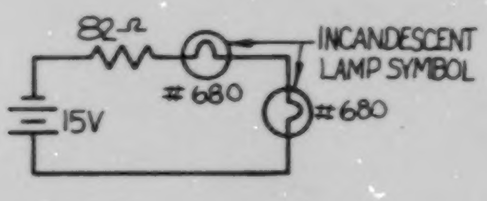
5. In a parallel circuit, if only one resistor is removed, the currents in the others

   a. stay the same.
   b. go to zero.
   c. increase.
   e. are removed.

## Task A Series Circuits

Use the 15 volt source or set the adjustable source to 15V. Have your instructor check that the voltage is correct.

Connect the resistor and pilot lamps in series as shown on the schematic using the interconnecting leads. Have your instructor check your connections.



Connect the voltage source and notice that both lamps are lighted. Have your instructor check that your connections are correct and that the lamps are working properly.

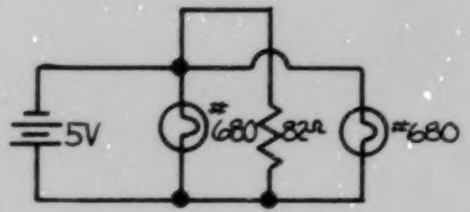
Remove any one interconnecting wire and notice that both lamps go out. This indicates that the current was lost in all parts of the circuit.

## Task B Parallel Circuit

Use the 5 volt source or lower the adjustable source to 5V. Have your instructor check that the source you are now using is 5 volts.

Connect the resistor and pilot lamps in parallel according to the schematic.

Notice that both lamps are lighted when the source is attached.



Have your instructor check your connections and that the lamps are working properly. Remove one of the lamps from the circuit leaving both ends of the resistor and the other lamp still connected to the source.

Notice that the remaining lamp is still lighted. This indicates that the current was lost only in the lamp that was removed and not in any other parts of the parallel circuit.

## Final Test

1. Components connected such that the same current flows in all of the components are connected in __________.

2. Components connectd such that the same voltage is across each of the components are connected in __________.

3. In a series, if a connection between two components is broken, the __________ goes to zero in every component in the circuit.

4. In a parallel circuit, if one of the resistances is removed, the currents in each of the other resistances __________.

## Final Evaluation

| | OK | Re-Do |
|---|---|---|
| Task A | | |
| Circuit is wired according to the circuit diagram | ________ | ________ |
| Task B | | |
| Circuit is wired according to the circuit diagram | ________ | ________ |
| Final Test questions answered correctly | ________ | ________ |

## Answers

### Self-Test

1. (b) schematic diagram
2. (a) current
3. (c) voltage
4. (d) goes to zero
5. (a) stays the same

INSTRUCTIONAL LEARNING SYSTEMS

# 2.6

## READING SCALES

## Goal:

The apprentice will be able to read scales of electrical measurement instruments.

## Performance Indicators:

1. Read voltmeter scale.
2. Read ammeter scale.
3. Read ohmeter scale.

# BASIC ELECTRONICS

## Reading Scales
## EL-BE-12

Test Draft
September 1981

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## Objectives

Given:

Information sheets

A volt-ohm-milliammeter

The student will:

Correctly record measured value indicated by drawing of each scale.

Correctly identify what number scale should be used with each setting of the range switch.

## Directions

Obtain the following:

VOM

## Learning Activities

______ Read Information Sheets.

______ Do Self-Tests.

______ Do Final Test.

______ Do Task.

______ Obtain Final Evaluation.

# Information Sheet No. 1

The ability to read meters properly is very important to the electronic technician. Much time can be lost by not using the meter or by inaccurate readings. Although reading scales is not difficult, it is very easy to make a mistake.

Scales you are already used to reading are rulers, clocks, and automobile speedometers. Meters are used to measure voltage (volts), current (amperes), and resistance (ohms). A "needle" or "pointer" moves to a position over the markings on the meter face to indicate the amount of current flowing through the meter.

The markings on a meter face are similar to the markings on the face of a clock.

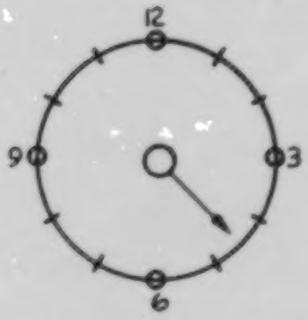


Figure 1-A

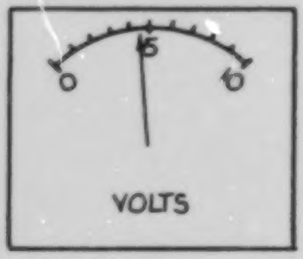


Figure 1-B

In Figure 1A, if the minute hand is removed from the clock, we would estimate the time as being 4:30 because the hour hand is halfway between 4 and 5.

In Figure 1B the meter needle is pointing halfway between the five and the next lower mark on the face of the meter. By counting the equally spaced marks we can assume that the reading would be 4.5 volts. It would be volts because the name on the meter indicates this.

Using this reasoning, determine the voltages indicated when the meter needle points to the following points.

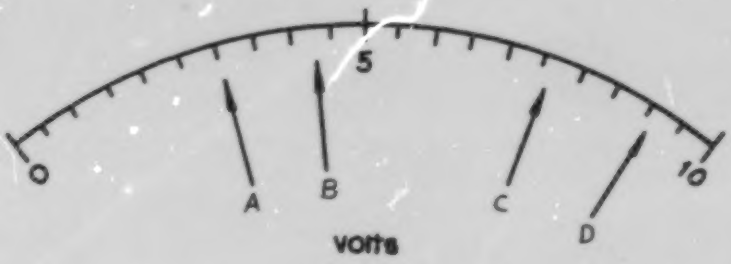


Figure 2

In Figure 2, we find that pointer A is two equally-spaced marks to the left of the 5 volt mark. Since there are ten marks between the zero and ten, each mark equals 1 volt. Counting from the 5 volt mark to the left, we see that the first two marks represent the pointer positions for 4 volts and 3 volts. Therefore, pointer A reads 3 volts. Pointer B, however, is between the 4 and 5 volt marks. By estimating, we can see that it is about 1/4 of a division greater than 4 volts. This voltage can be estimated as 4.25 volts. Pointer C is half a division above 7 volts or at 7.5 or 7 1/2 volts. Pointer D is at the ninth division and indicates 9 volts.

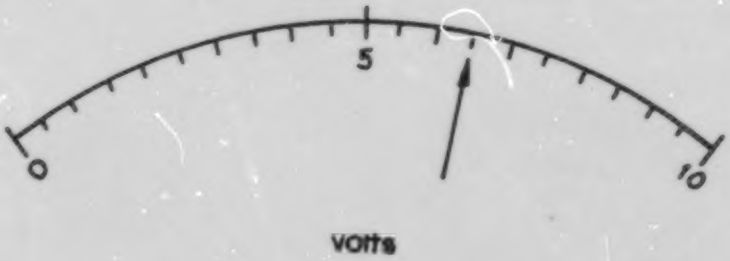
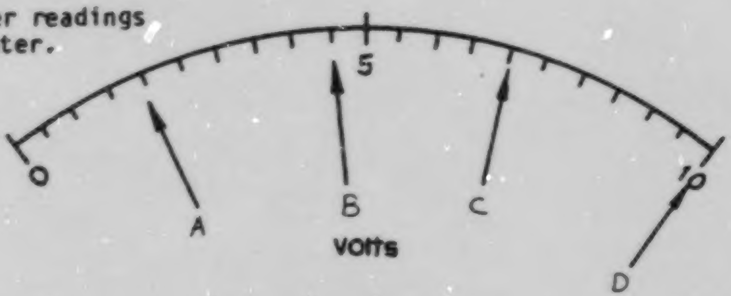


Figure 3

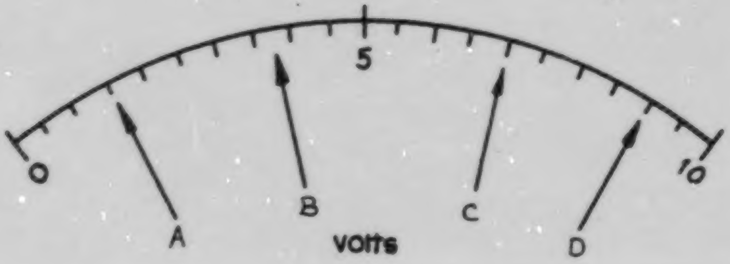
On the meter face in Figure 3, we see small marks between the larger marks. The small marks now indicate the half-volt graduations so we no longer have to guess where they are. The needle now indicates 6.5 volts.

## Self-Test No. 1

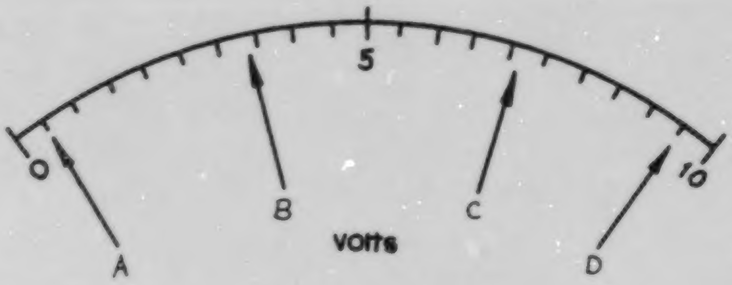
Give the meter readings for each pointer.


5
0
10
A
B
C
D
volts

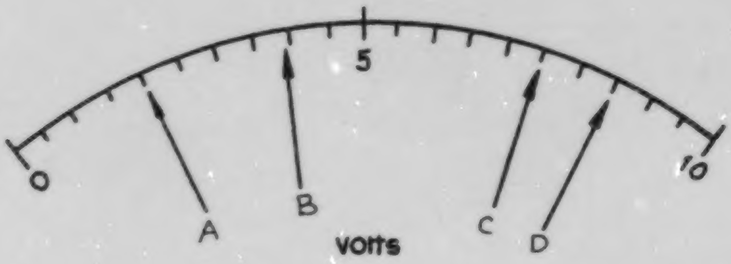
1. a.______
b.______
c.______
d.______


5
0
10
A
B
C
D
volts

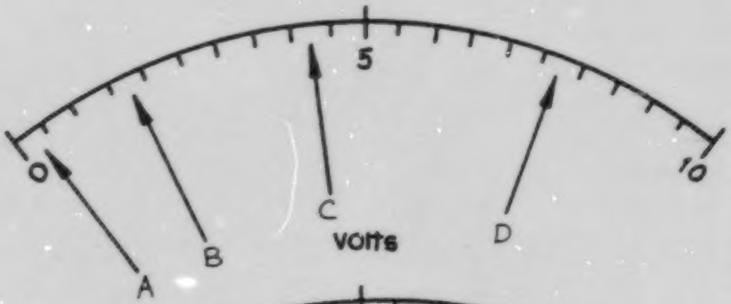
2. a.______
b.______
c.______
d.______


5
0
10
A
B
C
D
volts

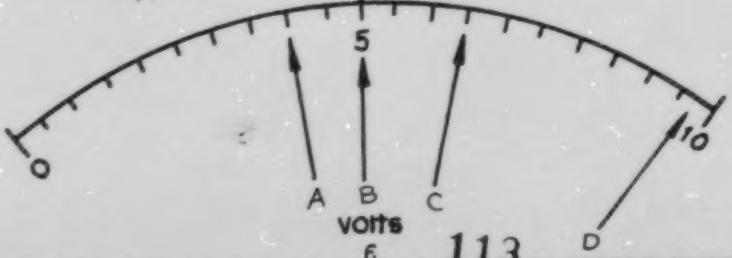
3. a.______
b.______
c.______
d.______


5
0
10
A
B
C
D
volts

4. a.______
b.______
c.______
d.______


5
0
10
A
B
C
D
volts

5. a.______
b.______
c.______
d.______


5
0
10
A
B
C
D
volts

6. a.______
b.______
c.______
d.______

# Information Sheet No. 2

Check your answers and make sure you understand before you proceed. VOMs or other multifunction meters have a range switch that extends the operating range of the meter. Without the range switch this voltmeter has only a 0-10V range. A range switch might look like Figure 4.

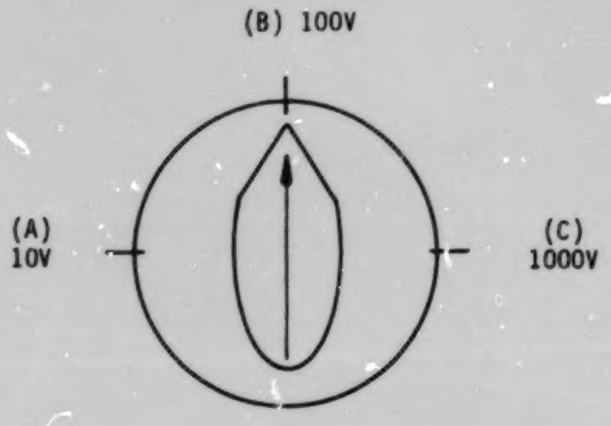
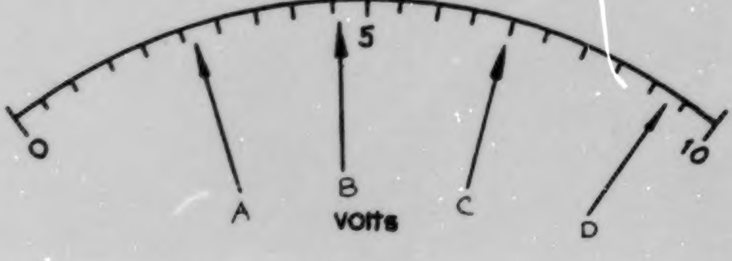


Figure 4

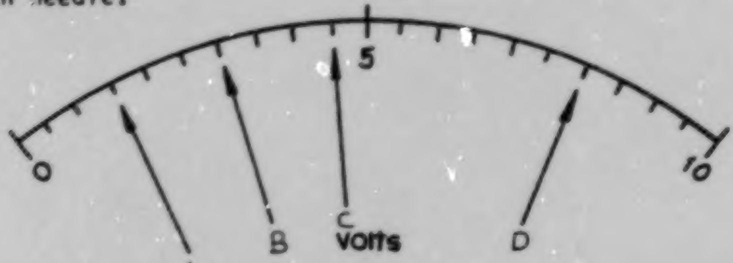
We now have two new ranges, B and C. With the range switch at B (100V) the meter will have a full-scale reading of 100 volts so we multiply all of our readings by 10; the pointer in Figure 3 would now be indicating 65 volts. If we switched to the 1000V range (C), the reading would indicate 650 volts (multiply the reading by 100). The range switch indicates the full scale range or maximum reading of the meter. Current or ampere ranges follow this same rule on ammeters.

| Range = | 10 | 100 | 1000 |
|---|---|---|---|
| | A = 2.6V | A = 26V | A = 260V |
| | B = 4.6V | B = 46V | B = 460V |
| | C = 7 V | C = 70V | C = 700V |
| | D = 9.3V | D = 93V | D = 930V |

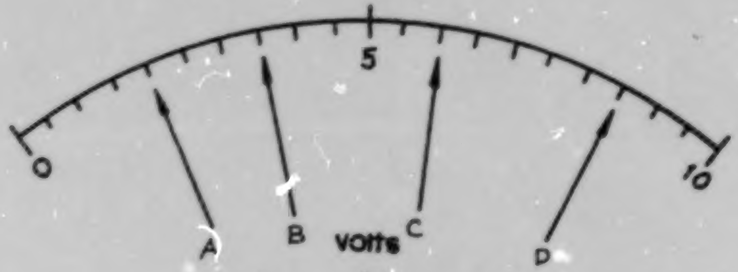


## Self-Test No. 2

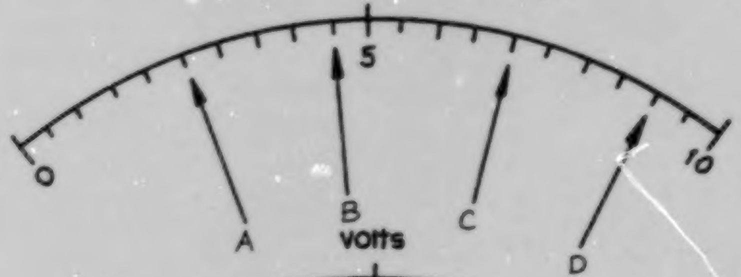
Assume the range switch is set as indicated for each meter. Tell the readings for each needle.


5
0
10
A
B
C
volts
D

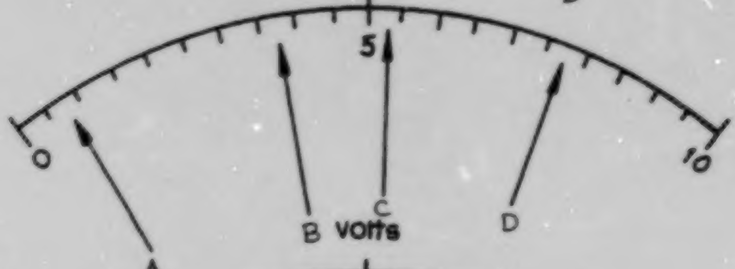
1. Range 100
a.________
b.________
c.________
d.________


5
0
10
A
B
volts
C
D

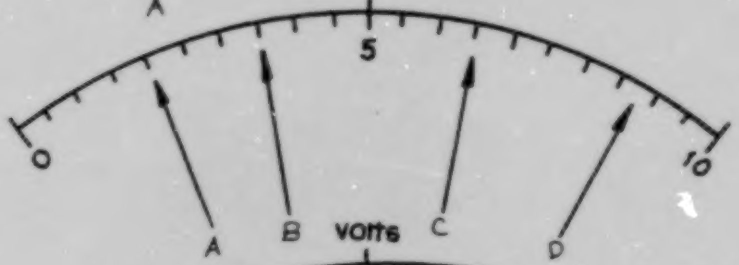
2. Range 1000
a.________
b.________
c.________
d.________


5
0
10
B
A
volts
C
D

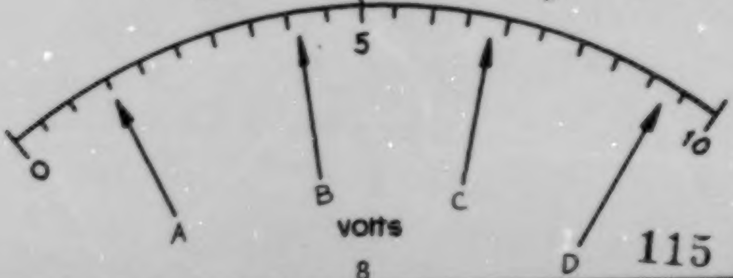
3. Range 10
a.________
b.________
c.________
d.________


5
0
10
C
B
volts
D
A

4. Range 100
a.________
b.________
c.________
d.________


5
0
10
A
B
volts
C
D

5. Range 1000
a.________
b.________
c.________
d.________


5
0
10
A
B
C
volts
D

6. Range 100
a.________
b.________
c.________
d.________

# Information Sheet No. 3

Other types of scales may also be printed on the face of the meter such as resistance or ohms (Ω) scale. Voltage or current meters draw the power to operate themselves from the circuit from which they are connected. However, the ohmmeter has an internal battery to provide current for operation.

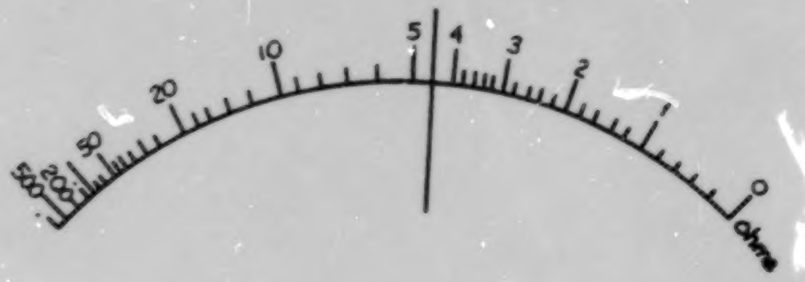
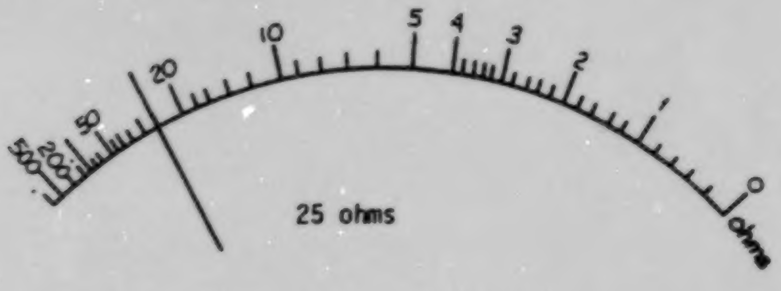
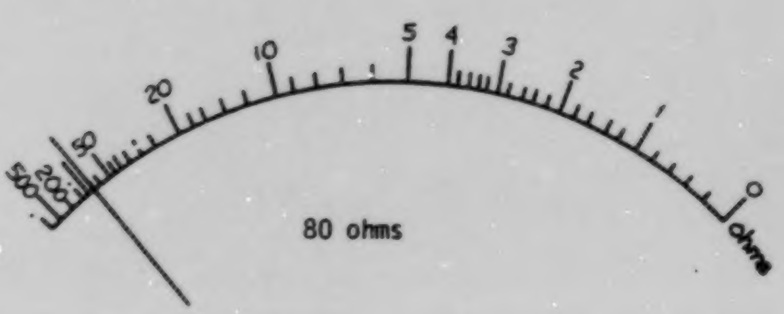

500
200
50
20
10
5
4
3
2
1
0
ohms

Figure 5

A typical ohmmeter scale would look like Figure 5. You will notice that the distance between 1 and 2 is not the same as the distance between 4 and 5. Because of this, we say that scale is nonlinear. The scale in Figure 3 is linear because there is equal spacing between numbers. In Figure 5 the ohmmeter needle is indicating 4.5 ohms of resistance.


500
200
50
20
10
5
4
3
2
1
0
ohms

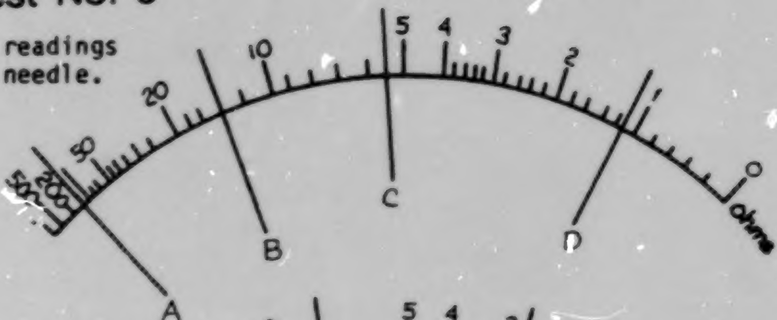
25 ohms


500
200
50
20
10
5
4
3
2
1
0
ohms

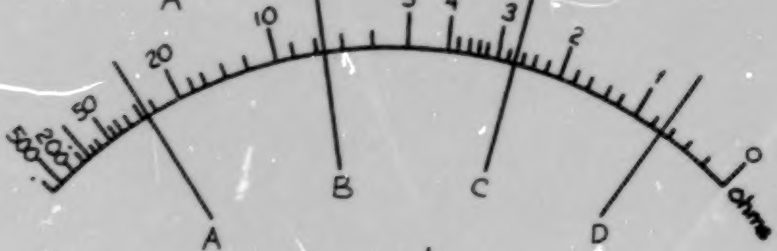
80 ohms

## Self-Test No. 3

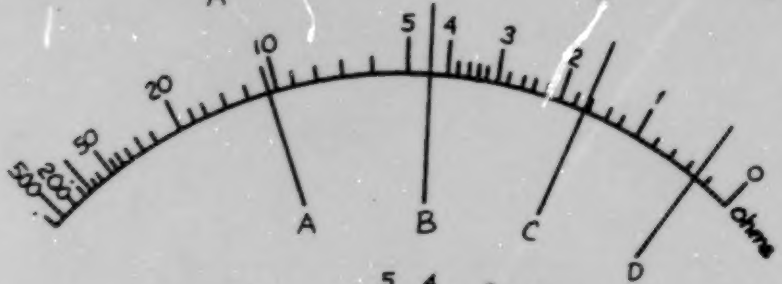
Give the readings
for each needle.


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

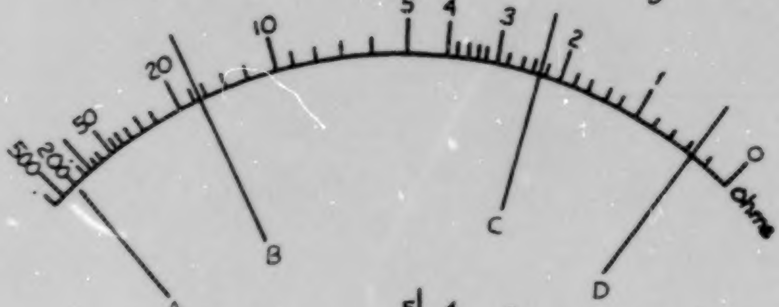
1. a.______
b.______
c.______
d.______


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

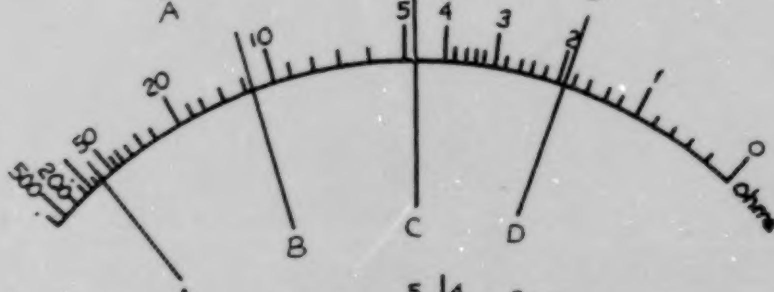
2. a.______
b.______
c.______
d.______


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

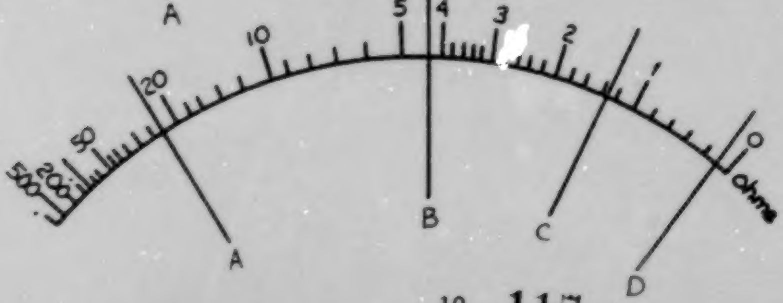
3. a.______
b.______
c.______
d.______


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

4. a.______
b.______
c.______
d.______


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

5. a.______
b.______
c.______
d.______


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

6. a.______
b.______
c.______
d.______

# Information Sheet No. 4

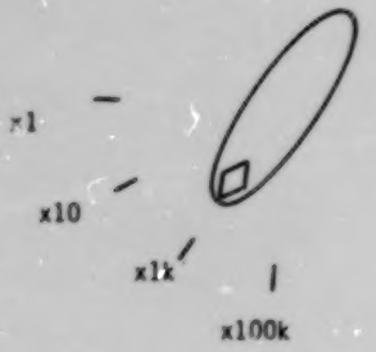


Figure 6

An ohms range switch might look like Figure 6.

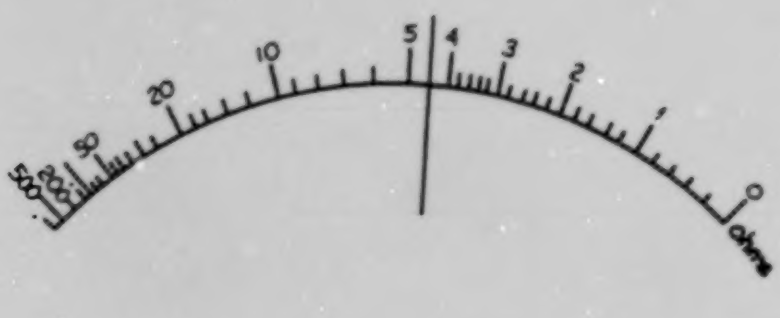


Figure 7

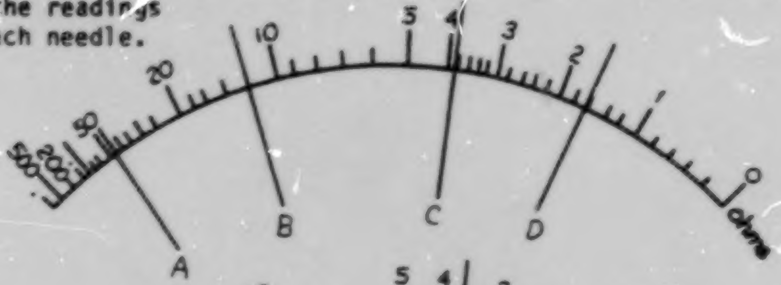
These positions mean that any reading made on the scale should be multiplied by the number of times indicated by the range switch. (x1 = times 1) (x10 = times 10; whatever the meter reads times 1, 10, 1000, or 100,000, etc.)

Our former reading of 4.5 ohms (Figure 5), would have been 4,500 ohms if the switch had been placed as shown above in Figure 6.

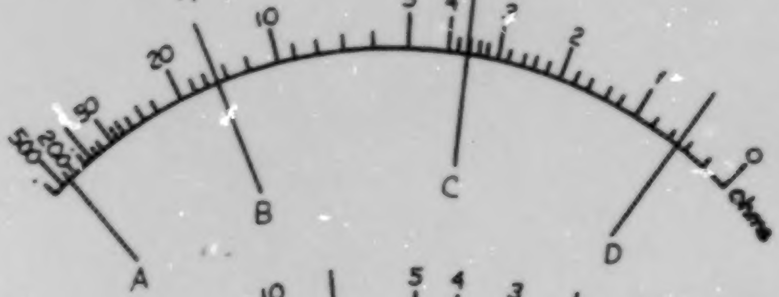
Remember k = thousand, so 1k is 1000.

## Self-Test No. 4

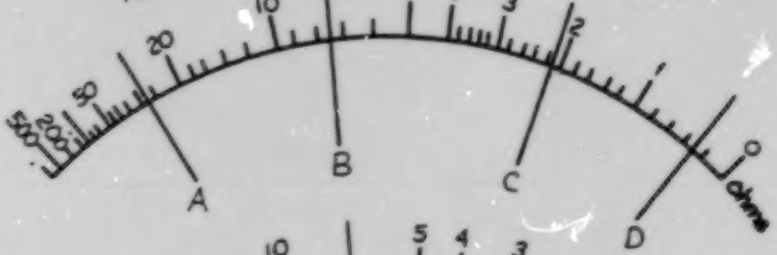
Assume the ohms range switch is set as indicated for each meter. Tell the readings for each needle.


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

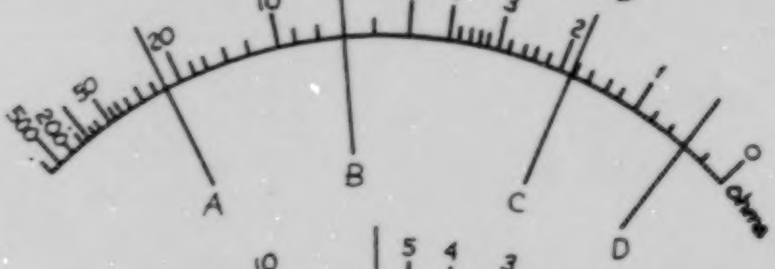
1. Range X1
a.________
b.________
c.________
d.________


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

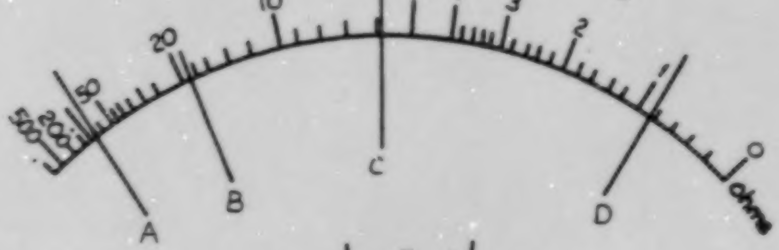
2. Range X100
a.________
b.________
c.________
d.________


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

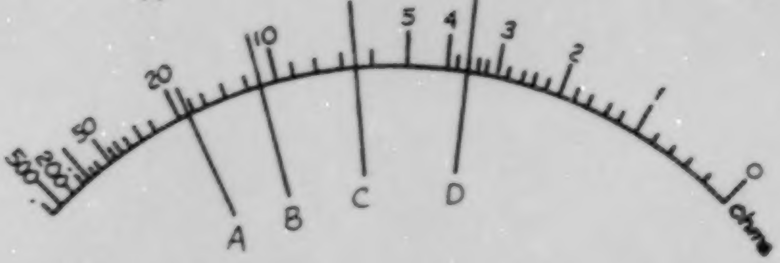
3. Range X10
a.________
b.________
c.________
d.________


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

4. Range X1K
a.________
b.________
c.________
d.________


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

5. Range X10K
a.________
b.________
c.________
d.________


500
200
50
20
10
5
4
3
2
1
0
ohms
A
B
C
D

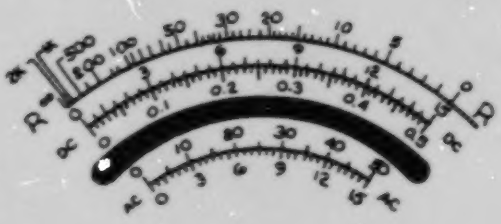
6. Range X100K
a.________
b.________
c.________
d.________

# Information Sheet No. 5

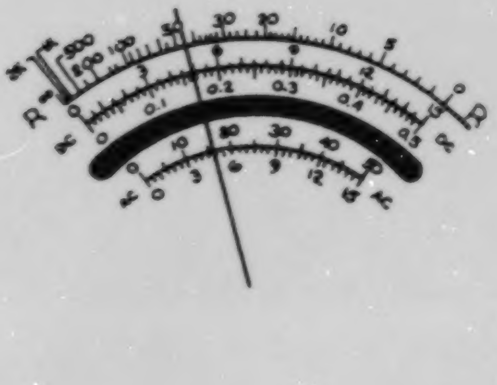
Some range switches may also indicate function (DC volts, AC volts, resistance, etc.). Multimeters have more than one function. Volt-ohm-milliammeters (VOMS) have three basic functions: the measurement of voltage and current (AC or DC) and resistance. Some VOMs may not have a current function. Function may be determined by input plugs for the test leads or a switch.

The first thing you must know when using a meter is what you wish to measure. The function of the meter must be set properly. Second, you must know where the range switch is set, and last, what the scale reads.

Let's try looking at a typical small meter scale all put together. Note the DC scale. The lower side goes from 0-0.5 and the upper side goes from 0 to 15. Your range switch will tell you which side to read. The AC scale also has a lower and upper side marked. Note that the R scale has only an upper side marked.


R
500
200
100
50
30
20
10
5
0
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
DC
0
DC
10
20
30
40
50
AC
0
3
6
9
12
15
AC

Based on function and range, this reading could mean many things. If the function were DC volts (DCV):


R
500
200
100
50
30
20
10
5
0
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
DC
0
DC
10
20
30
40
50
AC
0
3
6
9
12
15
AC

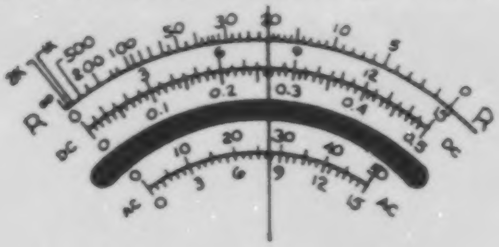
| To obtain reading: | RANGE |
|---|---|
| | 0.5 = 0.17V |
| Multiply 15 range reading by .1 | 1.5 = .5V |
| Multiply .5 range reading by 10 | 5 = 1.7V |
| | 15 = 5 V |
| Multiply .5 range reading by 100 | 50 = 17 V |
| Multiply 1.5 range reading by 100 | 150 = 50 V |
| Multiply .5 range reading by 1000 | 500 = 170 V |
| If the function were resistance (R): | R x 1 = 45 Ω |
| | R x 10 = 450 Ω |
| | R x 100 = 4.5k |
| | R x 1k = 45k Ω |
| | R x 10k = 450k Ω |

## Self-Test No. 5

Read the following meters according to the function and range indicated.

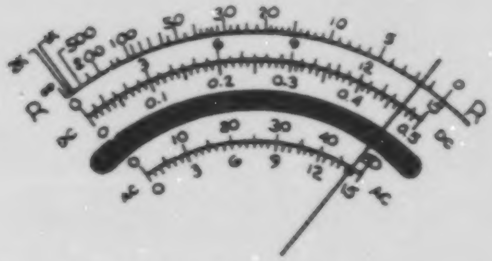
1. Function DCV
Range 15
Reading

______________


R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

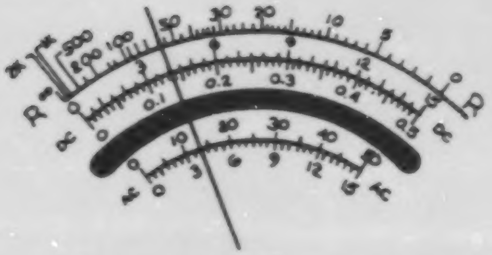
2. Function R
Range RxI
Reading

______________


R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

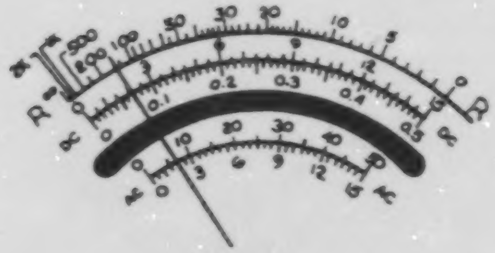
3. Function ACV
Range 500
Reading

______________


R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

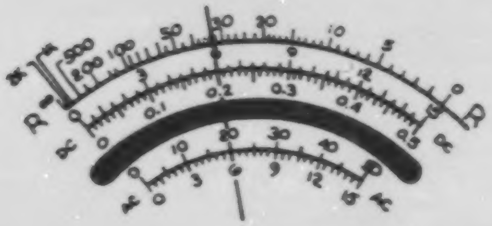
4. Function DCV
Range 5
Reading

______________


R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

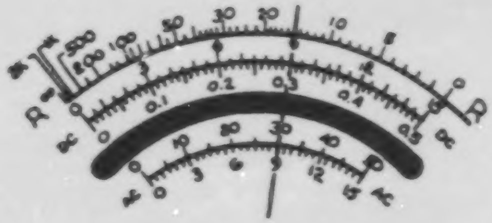
5. Function R
Range RXIK
Reading

______________

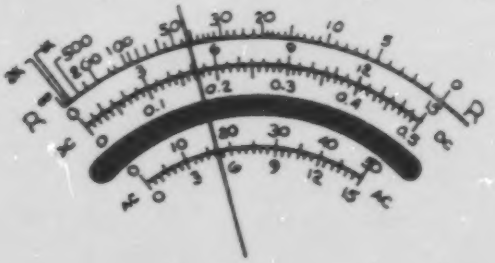

R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

6. Function DCV
Range 150
Reading

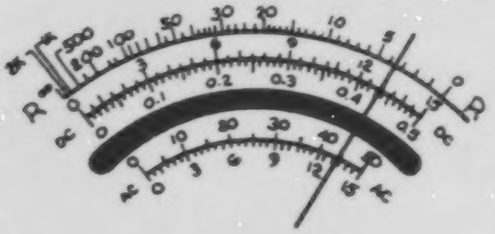
______________


R
2K 1K 500 200 100 50 30 20 10 5 0
0 .1 .2 .3 .4 .5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15

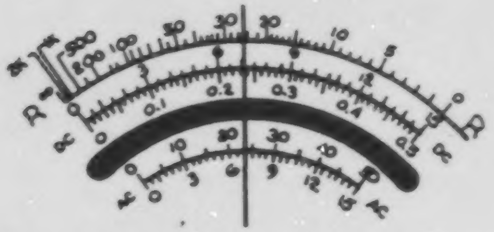
7. Function R
Range RX100
Reading ______________


2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

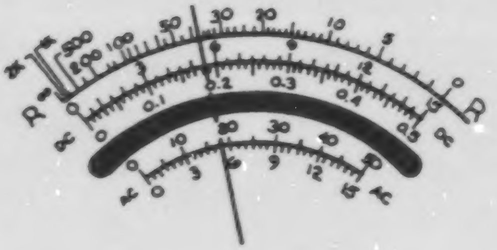
8. Function R
Range Rx1
Reading ______________


2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

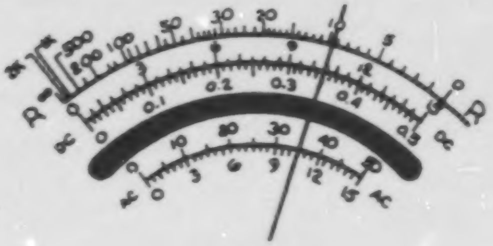
9. Function DCV
Range 50
Reading ______________


2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

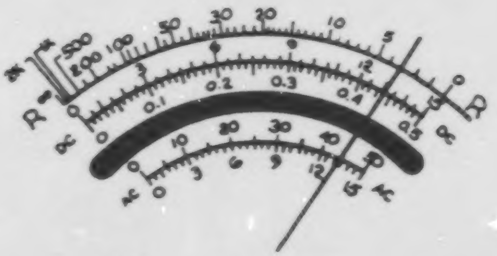
10. Function ACV
Range 50
Reading ______________


2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

11. Function DCV
Range 500
Reading ______________

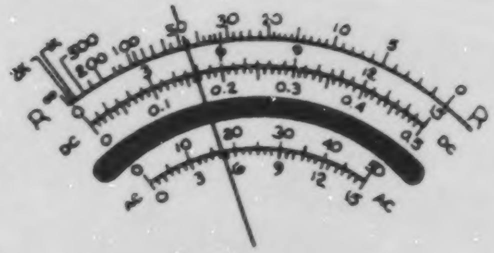

2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

12. Function DCV
Range 1.5
Reading ______________

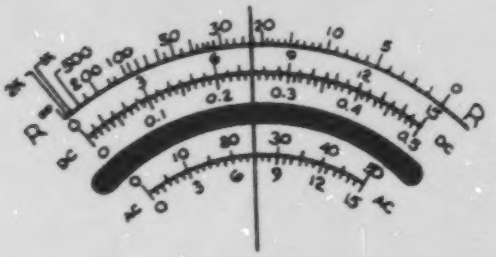

2K
1K
500
200
100
50
30
20
10
5
0
Ω
R
3
6
9
12
15
0.1
0.2
0.3
0.4
0.5
∞
0
10
20
30
40
50
AC

# Final Test

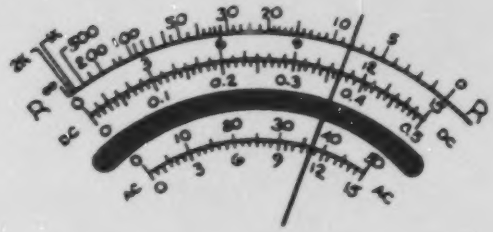
1. Function R
Range X1
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

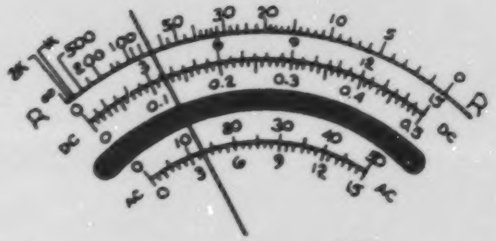
2. Function R
Range X10
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

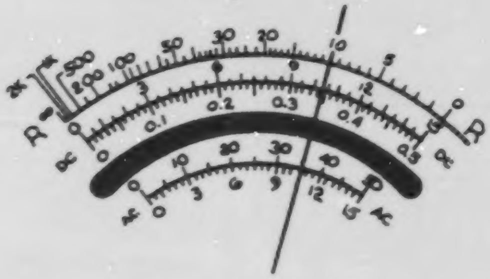
3. Function R
Range X100
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

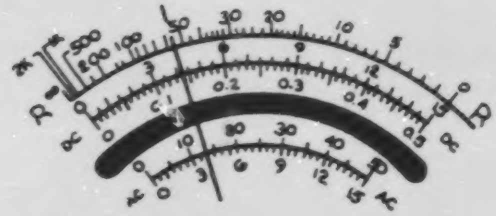
4. Function DCV
Range 15
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

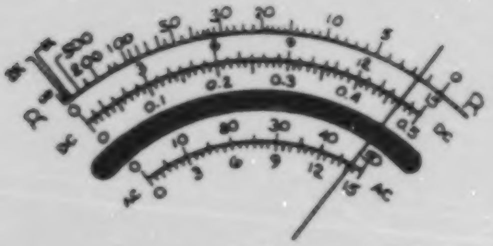
5. Function DCV
Range 5
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

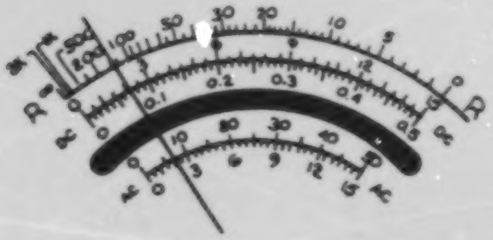
6. Function DCV
Range 15
Reading ________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC 0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

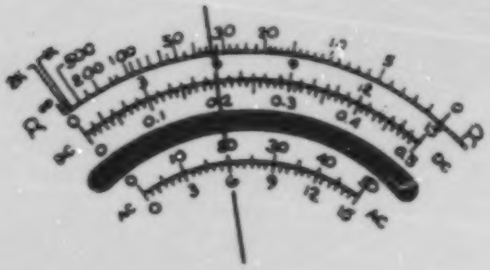
7. Function R
Range X1
Reading ____________


2K 1K 500 200 100 50 30 20 10 5 0 Ω
3 6 9 12 15
0 0.1 0.2 0.3 0.4 0.5
DC
0 10 20 30 40 50
AC 0 3 6 9 12 15 AC

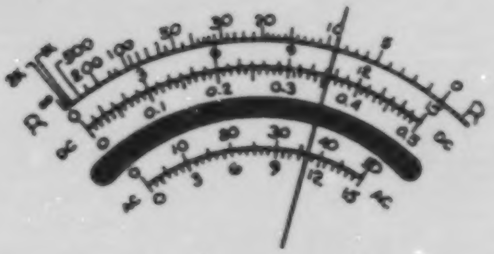
8. Function R
Range X1K
Reading ____________



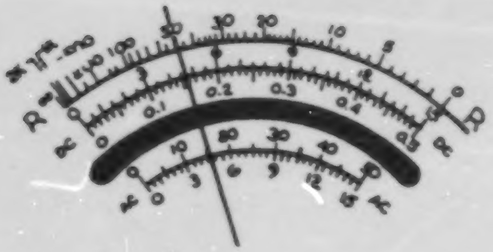
9. Function ACV
Range 500
Reading ____________



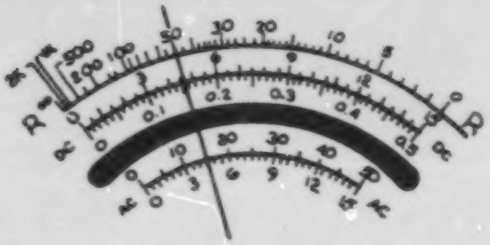
10. Function R
Range X10
Reading ____________



11. Function R
Range X100
Reading ____________



12. Function DCV
Range 50
Reading ____________



## Task

There are a number of different brands and models of VOMS. Many of them have different scales and ranges. To become familiar with your meter you should look over the scales, ranges, and function selection.

Obtain the following:

VOM

### Step I

Study the four top scales on the meter. Write in the space below the set of numbers that indicates the full scale reading for each range.

0 to __________ ohms scale

0 to __________ voltage or current

0 to __________ voltage or current

0 to __________ voltage or current

Notice how this meter uses a switch or test–lead jacks for different ranges and different functions. The functions, which are explained in more detail in the following package, are usually divided into the following areas:

DCV - used to measure DC voltage
ACV - used to measure AC voltage
Ω - used to measure resistance
DCmA - used to measure current

Within each function will be several ranges beginning with very low values and ending at very high values.

### Step II

List the number of ranges for each function from your meter.

| DCV | ACV | DCmA | Ω |
|---|---|---|---|
| 0 to | 0 to | 0 to | R x |
| 0 to | 0 to | 0 to | R x |
| 0 to | 0 to | 0 to | R x |
| 0 to | 0 to | 0 to | R x |

## Step III

Complete the chart below by listing the range for every function, the number you would use on each range and how you would modify the number to fit each range so that the number would indicate the correct value of measurement.

Example: Say your meter has a scale of 15 on DC volts, and your range was set to 150, you would fill out the chart like this:

| FUNCTION | RANGES | NUMBER SCALE USED | EACH NUMBER IS MULTIPLIED BY |
|---|---|---|---|
| DC Volts | 150 V | 0 to 15 | 10 |

| FUNCTION | RANGES | NUMBER SCALE USED | EACH NUMBER IS MULTIPLIED BY |
|---|---|---|---|
| Ohms | R x________ | 0 to __________ | |
| | R x________ | 0 to __________ | |
| | R x________ | 0 to __________ | |
| | R x________ | 0 to __________ | |
| DC Volts | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| AC Volts | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| | __________V | 0 to __________ | |
| DCmA | __________mA | 0 to __________ | |
| | __________mA | 0 to __________ | |
| | __________mA | 0 to __________ | |
| | __________mA | 0 to __________ | |

## Step IV

Get your instructor's evaluation of this task.

# Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Chart filled in correctly. | ______ | ______ |

## Answers

Your answers may not be identical to these, but if they are within a 5 percent range they will be considered correct.

### Answers to Self-Test #1

1. a. 2 V
   b. 4.5 V
   c. 7 V
   d. 10 V

2. a. 1.5 V
   b. 3.75 V
   c. 7 V
   d. 9 V

3. a. .5 V
   b. 3.35 V
   c. 7.25 V
   d. 9.5 V

4. a. 2 V
   b. 4 V
   c. 7.5 V
   d. 8.5 V

5. a. .25 V
   b. 1.75 V
   c. 4.25 V
   d. 7.75 V

6. a. 4 V
   b. 5 V
   c. 6.5 V
   d. 9.75 V

### Answers to Self-Test #2

1. a. 15 V
   b. 30 V
   c. 45 V
   d. 80 V

2. a. 200 V
   b. 350 V
   c. 600 V
   d. 850 V

3. a. 2.5 V
   b. 4.5 V
   c. 7 V
   d. 9 V

4. a. 7.5 V
   b. 37.5 V
   c. 53.5 V
   d. 75 V

5. a. 200 V
   b. 350 V
   c. 650 V
   d. 875 V

6. a. 15 V
   b. 41 V
   c. 68.5 V
   d. 94.5 V

### Answers to Self-Test #3

1. a. 150 Ω
   b. 14 Ω
   c. 5.5 Ω
   d. 1.19 Ω

2. a. 30 Ω
   b. 7.8 Ω
   c. 2.65 Ω
   d. .75 Ω

3. a. 10.1 Ω
   b. 4.5 Ω
   c. 1.6 Ω
   d. .3 Ω

4. a. 250 Ω
   b. 17 Ω
   c. 2.21 Ω
   d. .39 Ω

5. a. 53 Ω
   b. 11.7 Ω
   c. 4.75 Ω
   d. 1.9 Ω

6. a. 22.5 Ω
   b. 4.25 Ω
   c. 1.24 Ω
   d. .145 Ω

### Answers to Self-Test #4

1. a. 45 Ω
   b. 12 Ω
   c. 3.8 Ω
   d. 1.6 Ω

2. a. 3500 Ω
   b. 1500 Ω
   c. 360 Ω
   d. 425 Ω

3. a. 275 Ω
   b. 74 Ω
   c. 21.8 Ω
   d. 3 Ω

4. a. 22.5 Ω
   b. 7 k Ω
   c. 1.8 k Ω
   d. .4 k Ω

5. a. 750 k Ω
   b. 190 k Ω
   c. 60 k Ω
   d. 8.25 k Ω

6. a. 1900 k Ω
   b. 1150 k Ω
   c. 700 k Ω
   d. 360 k Ω

### Answers to Self-Test #5

1. 8 V
2. 1.5 Ω
3. 135 V
4. .6 V
5. 32.5 k Ω
6. 90 V
7. 4450 Ω
8. 3.5 Ω
9. 23.5 V
10. 18.5 V
11. 350 V
12. 1.05 V

INSTRUCTIONAL LEARNING SYSTEMS

# 2.7

## USING A VOM

### Goal:

The apprentice will be able to use a VOM for electrical measurement.

### Performance Indicators:

1. Identify parts of a VOM and their functions.
2. Measure voltage with VOM.
3. Measure resistance with VOM.
4. Measure current with VOM.

# BASIC ELECTRONICS

# Using a VOM
## EL-BE-13

Test Draft
September 1981

## Acknowledgment

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## Objectives

Given:

Information Sheets.

A VOM, complete with resistors and a power source.

The student will:

Answer 6 test questions on the basic parts of the meter.

Complete a Task for measuring DC voltage.

Complete a Task for measuring AC voltage.

Complete a Task for measuring resistance.

Complete a Task for measuring current.

## Directions

Obtain the following:

VOM.

A resistor assortment.

A voltage source (this unit has been preassembled by your instructor).

## Learning Activities

_____ Read the Key Words list.

_____ Read the general description of the VOM in the Information Sheets.

_____ Complete the Self-Test on the basics of the VOM.

_____ Complete a Task on measuring DC voltage.

_____ Complete a Task on measuring AC voltage.

_____ Complete a Task on measuring resistance.

_____ Complete a Task on measuring current.

_____ Obtain Final Evaluation.

## Key Words

VOM: Abbreviation for volt-ohm-milliammeter. A meter than can measure voltage, current, and resistance.

Polarity Switch: A switch which selects +DC or -DC depending on whether you are measuring positive or negative voltage. The + indicates a positive voltage and the - indicates a negative voltage.

Function-Range Switch: A switch which selects the function of current, voltage, or resistance and the maximum amount to be measured.

Ohms-or Zero-Adjust: A knob used to adjust the meter when measuring resistance. Since the battery inside your meter supplies power to the circuit when you are measuring resistance, adjustments have to be made for the various conditions of the battery.

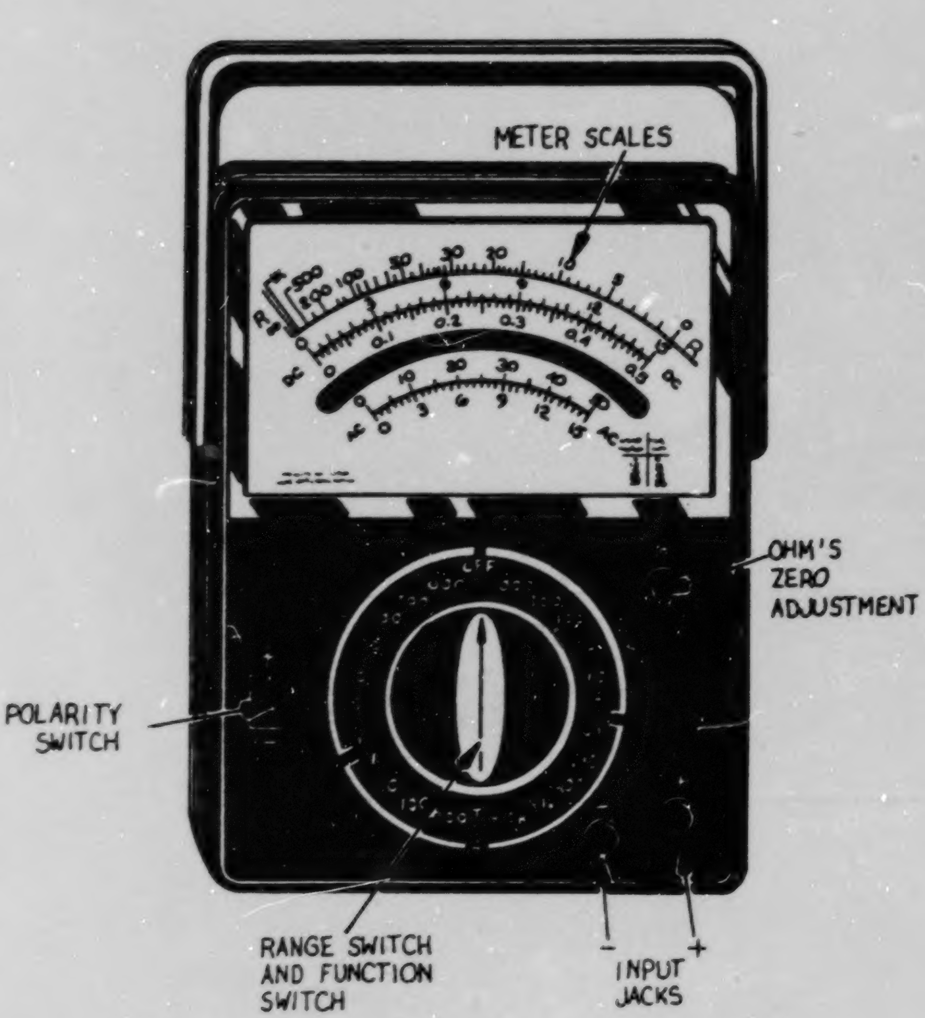
Input Jacks: The place where the test leads are inserted—the red lead going into the V-Ω-A jack and the black lead going into the "common" jack.

Meter Scales: The lines marked with small divisions that show the amount measured. A ruler is a type of scale used to measure distance. A meter scale is a type of scale used to measure voltage, current, or resistance.

Test Leads: The wires that are used to connect different parts of a circuit to the meter to make a measurement.

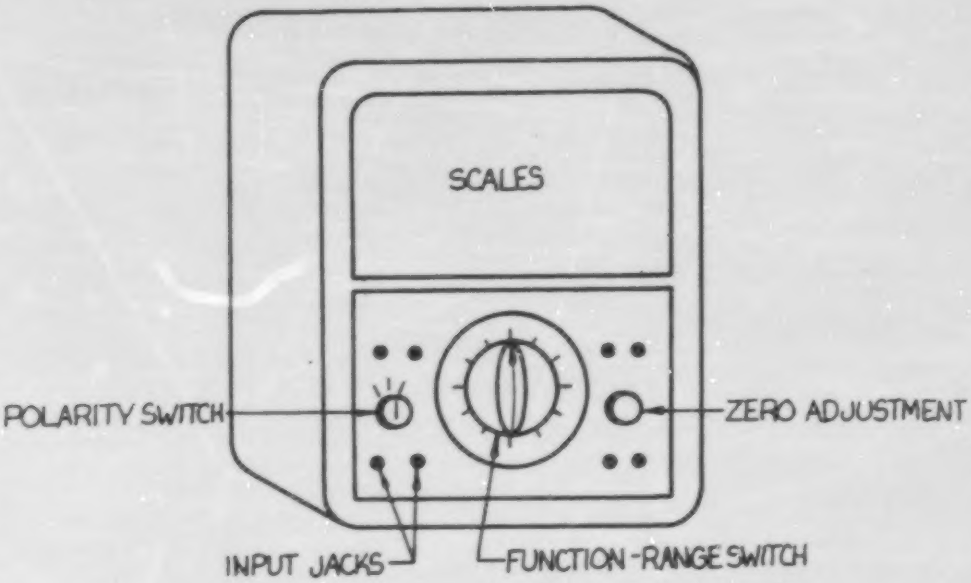
## Information Sheet No. 1

General description of the volt-ohm-milliammeter. Commercial models of the volt-ohm-milliammeter (VOM) multimeter are able to measure direct and alternating voltages, direct current, and resistance. Additional functions are sometimes included. A wide variety of models are available.


METER SCALES
OHM'S ZERO ADJUSTMENT
POLARITY SWITCH
RANGE SWITCH AND FUNCTION SWITCH
−
+
INPUT JACKS

Most VOMS have several features in common. They are the following:

1. Polarity Switch selects +DC, -DC or AC depending on what it is you are going to measure. (See drawing for a typical example.)



2. Function-Range Switch selects the function (current, voltage, or resistance) and the range to be measured (100 mA or 10 mA, etc.). Only one of the ranges can be selected at one time.

3. Ohms Adjust (sometimes called zero ohms) is a variable resistance in the ohmmeter circuit. It is used to adjust the meter when measuring ohms to allow for changes in the voltage of the internal batteries. It is adjusted with the range switch on any resistance range so that the needle points to zero on the ohms scale (usually on the right side) when the leads are touched (shorted) together. The meter is adjusted to zero because at this time there is no resistance between the leads of the meter. This adjustment must usually be made whenever the resistance range is changed.

4. Input Jacks are the places on the meter where the test leads are connected. They are all clearly labeled, and if there is any question as their usage, consult the Operator's Manual for specific information. Most measurements are made by using the + and - (common) jacks.

5. Meter Scales are like a curved ruler and are marked with small divisions from which values may be read.

6. Test Leads are the wires that are used to connect the meter to the circuit under test. The red lead is considered positive (+), and the black lead is negative (-) or common. Connecting these leads correctly is called observing correct polarity. Incorrect polarity in DC circuits will cause the needle to deflect or move backwards, and damage could result. In AC circuits, polarity is not important.

All VOMS have one thing in common: they have a very sensitive meter movement. The meter's range and function are changed to measure various voltages and currents.

## Self-Test

General description of the volt-ohm-milliammeter

(Select from answers at bottom of page.)

1. Polarity Switch ______________________
2. Function-Range Switch __________________
3. Ohms Adjust ________________________
4. Input Jacks ________________________
5. Meter Scales _______________________
6. Test Leads _________________________

a. Used to adjust the meter when measuring ohms.

b. Wires that are used to connect the meter to the circuit.

c. Selects +DC, -DC, depending on what you are going to measure.

d. Marked with small divisions from which values may be read.

e. Selects voltage, current, or resistance and the maximum amount to be measured.

f. Places on the meter where the test leads are connected.

# Information Sheet No. 2

General procedure for using a VOM to measure voltage

The following is an outline of the basic parts of the meter used to measure DC voltages and the general procedure for measuring voltage with a VOM or multimeter. This will fit the most common types of meters with few variations.

1. Needle Adjustment For the meter indications to be as accurate as possible, the needle should rest directly over zero on the left side of the scale when the meter is disconnected. If the needle does not sit directly over zero on the left, it should be adjusted only by someone who knows the proper method of setting the meter.

2. Lead Placement Place the leads in the proper input jacks. The leads are connected red to positive (+), and the black to negative (-) or common.

3. Polarity Switch If your meter is equipped with a polarity switch, turn it to the position that represents the type of voltage you are measuring (AC or DC). If the voltage under measure is DC, have the switch on DC+ for measurements. The DC- is used only in special cases such as when you are measuring negative DC voltages. On meters that have "AC volts" and "DC volts" included on the range switch, be sure to select the correct ranges as well as the type of voltage.

4. Function-Range Switch Turn this switch to the highest voltage range. This step should be done when measuring any voltages unless you are definitely sure that the voltage will not exceed the range voltage.

5. Connecting the Meter Always turn off the power when making a connection to provide for personal safety. The leads are connected across (in parallel with) the part of the circuit under test. In DC measurements, you connect the black lead to the most negative point of the circuit and the red lead to the most positive point. If you are unsure of the connection, consult your instructor.

6. Circuit On If the voltage reading is within a lower range (in the lower 1/4 of the scale), turn the range switch down until the needle moves above the 1/4 scale mark. Be careful not to turn down more than one range step at a time.

7. After the reading has been made, turn the circuit off, remove the meter, and turn the meter to "OFF" or to the highest range to protect the meter.

IMPORTANT

General precautions should be followed with the VOM as with any other meter. Some of these are as follows:

> When measuring voltage, the circuit is necessarily alive, so keep one hand in your pocket. This is a safety precaution. If you use two hands connecting the meter to a circuit, you are placing yourself in parallel with the circuit and may have a short circuit through your body. When electricity passes through your heart, it can, and probably will, cause severe shock and possibly death. Do not be afraid of electricity; RESPECT IT!

When measuring voltage, do not have the meter set to measure ohms or milliamps, as you will damage the meter.

## Task A

Equipment:

One VOM
One DC voltage source

Procedure:

1. Set meter function range switch for highest +DC volts range, and hook up test leads (red to plus and black to minus). Have instructor check.

2. Plug in your voltage source and locate the "common" and 30 VDC terminals.

3. Connect your black lead to the "common" terminal and your red lead to the "+" terminal.

4. Does your meter needle move? If not, you may be on too high a range. Slowly switch the range switch to lower ranges one at a time until your needle moves up to the center part of the scale. DO NOT GO OFF SCALE OR YOU MAY DAMAGE YOUR METER!! (When the needle starts to move up onto the scale, stop and read the value to make sure it does not exceed the range of the next lower range). USE THE SCALE THAT "FITS" YOUR RANGE SETTING.

   How much voltage did you measure? ____________________

   If you measured about 30 volts DC, then continue on and measure the remaining DC voltages as marked on the source. Record your measurements in the chart below.

| TERMINAL VOLTAGE | MEASURED VOLTAGE | INSTRUCTOR'S OK |
|---|---|---|
| 30 VDC | | |
| 18 VDC | | |
| 12 VDC | | |
| 5 VDC | | |

5. Get your instructor's evaluation.

   This may seem very easy to you, but it takes a lots of practice to make accurate voltage measurements, and many mistakes can be made - TAKE TIME and CARE.

# Task B

Equipment:

One VOM
One AC voltage source

Procedure:

1. Set meter function-range switch for highest AC range. Hook up test leads in proper input jacks (have instructor check).
2. Plug in voltage source and locate the AC terminals.
3. Connect test leads to AC terminals of your voltage source (on AC, polarity does not matter).
4. Observe scale and reduce ranges slowly one step at a time until the needle rests in the upper half of the scale.
5. Record your reading and range for AC.

| | RANGE | VOLTAGE |
|---|---|---|
| AC | | |

Have instructor evaluate.

## Information Sheet No. 3

General Procedures for using a VOM to measure resistance

The following is an outline of the basic parts of the meter used to measure resistance.

When measuring resistance with the VOM or multimeter, it is necessary to follow certain general procedures. These are as follows:

1. Lead Placement Place the leads into the proper input jacks. These will be the + (or V-Ω-A) and - jacks, as used for most other measurements.

2. Polarity Switch This switch is placed in the DC+ position, as the meter will not work properly when on AC or DC-.

3. Meter Zero The meter must be set to zero to measure resistance. Nearly all VOMs have the highest resistance where the smallest current flows. The highest resistance readings are, therefore, on the left of the scale, and the VOM usually does not have an adjustment for this side. The meter zero allows the operator to set the meter so most current is flowing when the resistance is zero. This adjustment is made as follows:

   Step a: With the range switch on the resistance range desired, touch the two leads together (short circuit).

   Step b: Move the zero adjustment so the needle points over the extreme right hand side to zero on the ohms scale.

   Step c: Disconnect the leads. Do not leave the leads shorted together, as this will run down the battery in the meter!

4. Function-Range Switch This switch may be placed on any range desired for resistance measurements. The range switch selects the multiplier for the meter. To find the actual resistance of the circuit, take the reading from the meter scale and multiply it by the number on the range. For example, if the reading on the VOM is 2.2 and the range is R x 100, the value would be 2.2 times 100, or 220.

5. Read the meter scale and multiply by the number indicated on the range setting, and record the value if necessary. (If a range setting—adjustment is necessary for a good reading (in the center two-thirds of the scale), be sure to check zero ohms again at the new range setting).

6. When finished with the readings, turn the meter to the "OFF" position or to the highest voltage range to protect the meter.

## Task C

Equipment:

One VOM
One resistor assortment (at least 10 resistors)

Procedure:

You are going to measure the resistance of some resistors that may have a wide range of values. NOTE: All the ohms ranges go from zero to infinity ( ∞ ). There are two things to remember: 1) Your most accurate reading will be in the center two-thirds of the meter scale so you want to select the range that will get you in that area if possible. 2) You must "zero" your meter every time you change ranges. (See step 3).

1. Insert test leads into proper input jacks.
2. Select resistance range.
3. Zero your meter on this range.
    - A. Connect leads together (short).
    - B. Slowly turn "ohms adjust" knob until the needle is exactly over the zero of the ohms scale. If the needle won't go all the way to zero on a certain range (usually a lower range), have your instructor check it. You may need a new battery in your meter.
4. Touch the test leads to each end of the resistors and carefully read each value and chart below. Also list the color-code value for each.

| COLOR-CODED VALUE | METER READING |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |

Have your instructor evaluate.

# Information Sheet No. 4

General Procedure for Using a VOM to Measure Current

The following is an outline of the basic parts of the meter used to measure current.

When measuring current with a VOM, it is necessary to follow certain general procedures. Typical procedures for measuring milliamperes are as follows:

1. Lead Placement Place the leads in the proper input jacks. Usually the leads are connected to the + and - jacks, as before for milliamps. Other jacks for amps or for microamps are available when reading these respective values of current.

2. Polarity Switch This switch is to be on DC+, as the VOMs do not usually measure AC current.

3. Function-Range Switch Turn this switch to the highest range. This step should be done when measuring any current, unless you are definitely sure that the current will be less than maximum for a lower range.

4. Meter Connection To be measured, all of the current that flows through the component must also go through the meter. To make this possible, it is necessary to open the circuit and insert the meter in series. Do not connect as a voltmeter or ohmmeter or you will probably damage the meter. Assume we have the circuit of Figure 1, and we wish to measure the current at point B.

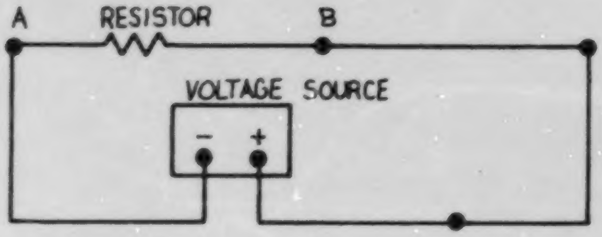


Figure 1

Break the circuit at point B as shown in Figure 2

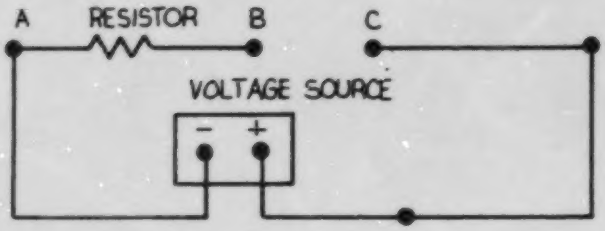


Figure 2

Connect the meter as shown in Figure 3 with the negative lead toward the negative side of the circuit (point B, in this case) and the positive lead to the positive side of the circuit (shown as point C).

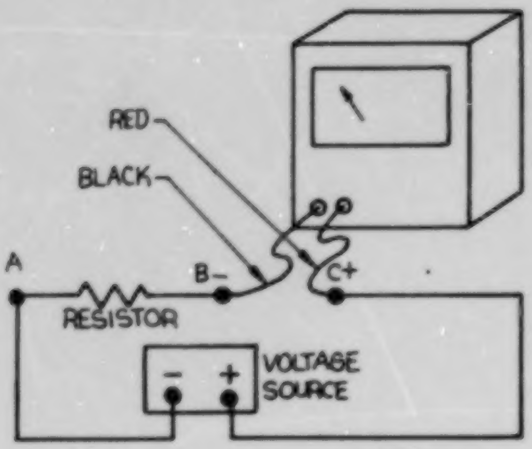

RED
BLACK
A
B−
C+
RESISTOR
−
+
VOLTAGE SOURCE

Figure 3

5. Voltage On With the voltage turned on, the current is flowing through the circuit. If the needle does not go above one quarter of the scale, turn the range switch down one range at a time until the needle moves into the middle or upper half of the scale. (Figure 4.)

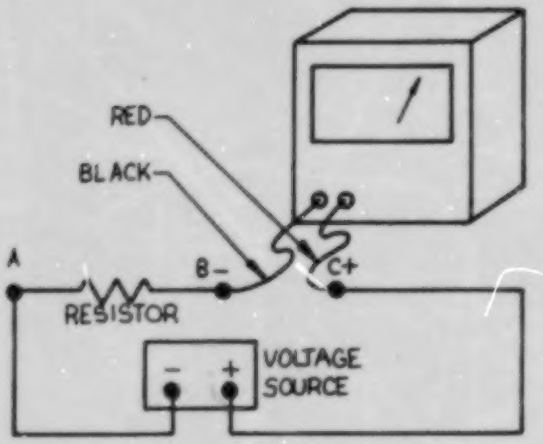
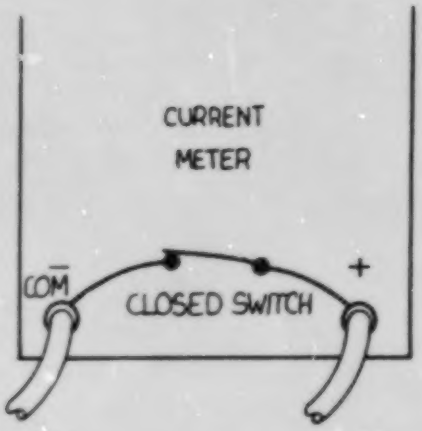

RED
BLACK
A
B−
C+
RESISTOR
−
+
VOLTAGE SOURCE

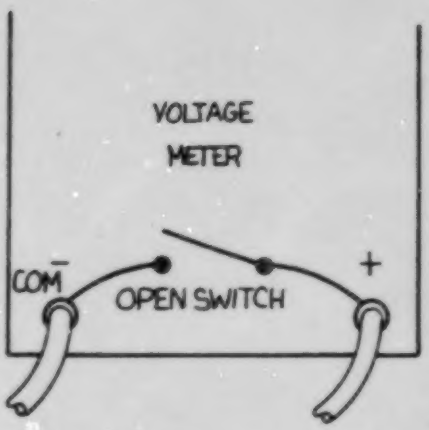
Figure 4

6. Voltage Off Turn off the voltage, remove the meter, and turn the meter "OFF" or to the highest voltage range to protect the VOM. Switching to the highest voltage range switches out the ohmmeter and the ammeter sections of the VOM. Both the ohmmeter and ammeter sections can be easily damaged by external voltages. Only switch to the ohmmeter or ammeter sections when you need them. Otherwise switch to "OFF" or to a high voltage range for protection of the meter.

IMPORTANT

Since it is very easy to damage the meter when attempting to measure current, it is important to use extreme caution when using the current function. Many meters measure only up to 1/2 amp (500 milliamps). So don't measure ANY CURRENT you are not sure is within the range of your meter!! (One-half amp is NOT MUCH.) Another common error is placing your test leads across a voltage drop (in parallel to the load). The current function on your meter acts like a short circuit and must be in series with the load, whereas your volt functions tend to act like an open switch.





## Task D

Equipment:

| | |
|---|---|
| One VOM | |
| One voltage source | |
| Four resistors, 1/2 watt | One 100Ω |
| | One 1k |
| | One 10k |
| | One 100k |

Procedure:

1. List the ranges on your meter for current (DC mA) starting with highest first.

HIGHEST ____________________

____________________

____________________

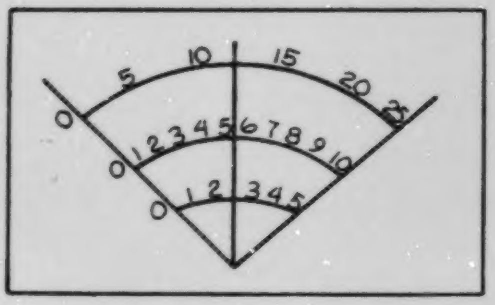
____________________

____________________

LOWEST ____________________

Now, in the right hand column, record the highest point on this scale that your needle can read to be able to switch safely to the next lower range. For instance, say you have ranges 500 mA, 250 mA, 100 mA, 50 mA, 10 mA, 5 mA.

| RANGES | HIGHEST SAFE READING AT WHICH TO SWITCH DOWN TO NEXT LOWER SCALE. |
|---|---|
| 500 mA | 250 |
| 250 mA | |
| 100 mA | |
| 50 mA | |
| 10 mA | |
| 5 mA | |



The highest safe point on the 500 mA scale would be 250 so we would put 250 in the right hand column. If the needle goes above that point, it would damage the meter if you switched to the next lower range.

Have your instructor check your understanding of this before proceeding.

2. Set current function to highest range and place test leads in proper input jacks.

3. Plug in voltage source and determine 'common' and 5 volt DC terminals. Connect your 100 resistor to the 5 volt terminal and your black test lead to the common terminal of your voltage source. DO NOT CONNECT YOUR RED TEST LEAD. Call instructor to check proper set up of the following:

_____ Meter range and function.

_____ Test lead connection at meter.

_____ Proper output terminal of voltage source.

_____ Correct resistor.

4. When approved, hook up red lead and adjust range switch CAREFULLY until you can make your reading.

5. Record this current: ____________________.

You should measure somewhere around 50 mA. If you do not get anywhere near this value, consult your instructor before proceeding.

If your reading checks out, proceed to use the remaining resistors. Record each measurement in the chart below.

| RESISTOR | CURRENT MEASURED | INSTRUCTOR'S OK |
|---|---|---|
| 100Ω | | |
| 1k | | |
| 10k | | |
| 100k | | |

## Final Evaluation

| PROPER READINGS ON: | OK | Re-Do |
|---|---|---|
| TASK A | | |
| TASK B | | |
| TASK C | | |
| TASK D | | |
| METER STILL WORKS PROPERLY | | |

When all checks indicate OK, proceed to the next learning package.

# Answers

## Self-Test Answers

1. c

2. e

3. a

4. f

5. d

6. b

INSTRUCTIONAL LEARNING SYSTEMS

# 2.8

## OHM'S LAW

## Goal:

The apprentice will be able to compute electrical problems through use of Ohm's Law.

## Performance Indicators:

1. Compute current from given voltage and resistance.
2. Compute resistance from given current and voltage.
3. Compute current from given voltage and resistance.

# BASIC ELECTRONICS

## Ohm's Law
## EL-BE-15

Test Draft
September 1981

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## Objectives

| Given: | The student will: |
|---|---|
| Ohm's Law | Complete a Final Test solving Ohm's Law problems with 80% accuracy. |
| | Complete a Final Test on Ohm's Law relationships with 80% accuracy. |
| Materials to perform a series of tasks | Complete a Task for current. |
| | Complete a Task for voltage. |
| | Complete a Task for resistance. |

## Directions

Obtain the following:

one circuit board

two 1K resistors (1,000 ohm)

one multimeter

one variable voltage power supply

## Learning Activities

_____ Study the Key Words list.

_____ Read the Information Sheets.

_____ Do the exercise on memorizing Ohm's Law.

_____ Do the Self Test on Ohm's Law problems.

_____ Do the Self Test on Ohm's Law equations.

_____ Do the Task on Ohm's Law for current.

_____ Do the Task on Ohm's Law for voltage.

_____ Do the Task on Ohm's Law for resistance.

_____ Do Final Tests I and II.

_____ Obtain Final Evaluation.

## Key Words

I: Math symbol for current

R: Math symbol for resistance

E: Math symbol for voltage

$I = \frac{E}{R}$ Ohm's Law equation for current when voltage and resistance are known.

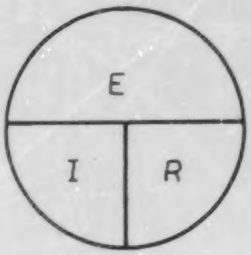
$R = \frac{E}{I}$ Ohm's Law equation for resistance when voltage and current are known.

$E = I\,R$ Ohm's Law equation for voltage when current and resistance are known.

Directly Proportional: A math relationship in an equation that results in a larger or smaller answer when the terms on the other side of the equation get larger or smaller.

Inversely Proportional: A math relationship in an equation that results in a smaller answer when the terms on the other side of the equation get larger, or a larger answer when the terms get smaller on the other side of the equation.

Ohm's Law Pie: A circle used to easily memorize each of the Ohm's Law equations. To find "I" you would put a finger over the "I" term and the remaining part would form the equation: $I = \frac{E}{R}$



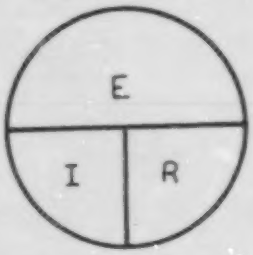
# Information Sheet

Voltage, resistance and current are related in a very special way. This relationship is stated in a law of electricity called Ohm's Law. Technically stated, the law reads as follows: "The current through a resistance is directly proportional to the voltage and inversely proportional the the resistance". Mathematically this is expressed as the equation $I = \frac{E}{R}$

Since there are three terms in the Ohm's Law relationship, I, E and R, three equations may be derived from this statement. The three equations are as follows:

| | |
|---|---|
| For Current | $I = \frac{E}{R}$ (E divided by R) (E ÷ R) |
| For Voltage | $E = IR$ (I times R) (I x R) |
| For Resistance | $R = \frac{E}{I}$ (E divided by I) (E ÷ I) |

A simple rule to memorize each equation involves using an Ohm's Law pie.



***MEMORIZE THIS***

To solve for voltage, you simply put a finger over the E and you get I x R, or E = IR.

To solve for current, put a finger over the I and you get $\frac{E}{R}$ or $I = \frac{E}{R}$.

To solve for resistance, put a finger over the R and you get $\frac{E}{I}$ or $R = \frac{E}{I}$.

Simply cover the letter you want to solve for and the remaining letters form your equation.

The basic use for Ohm's Law is to calculate for the following:

1. The voltage if we know the current and resistance. $E = IR$.
2. The resistance if we know the current and voltage. $R = \frac{E}{I}$.
3. The current if we know the resistance and voltage. $I = \frac{E}{R}$.

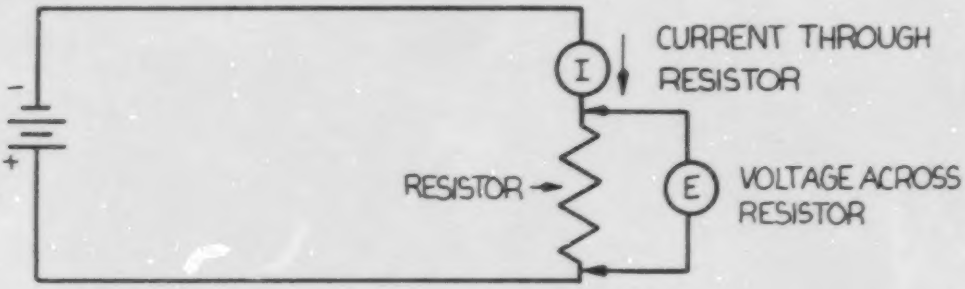
In addition you need to remember that when using Ohm's Law in a circuit you must use each term as follows:

I is the current through the resister.

E is the voltage across the resistor.

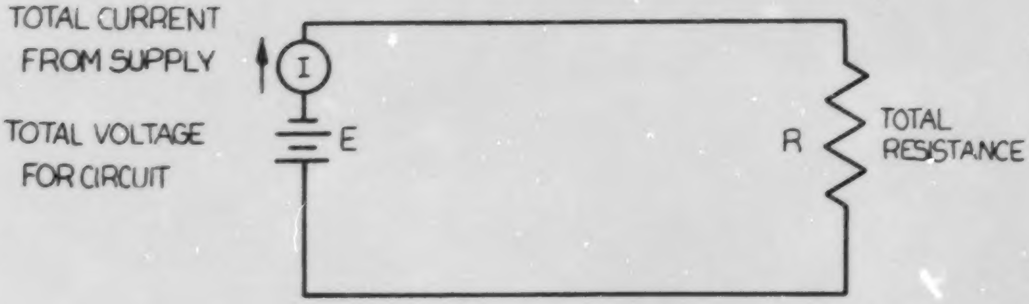
R is the value of the resistor.

***You must know two of the three terms of each equation to solve for the third.***



You may look at each of the three terms another way.

1. I is the total current through the entire circuit.
2. R is the total resistance of the entire circuit.
3. E is the total voltage applied to the circuit.


TOTAL CURRENT FROM SUPPLY
I
TOTAL VOLTAGE FOR CIRCUIT
E
R
TOTAL RESISTANCE

When solving for Ohm's Law equations remember to convert all values for resistance, voltage, and current to their basic units.

The basic unit for resistance is the ohm.

The basic unit for voltage is the volt.

The basic unit for current is the ampere.

To help you work problems using Ohm's Law, the equations will be presented showing all conversions to ohms, volts, and amps necessary to solve each equation. In the following circuit diagrams the symbol Ⓐ is used to represent the ammeter that is measuring current (I) in amps.

Now let's try a few problems using each equations to make sure you can follow the math involved.

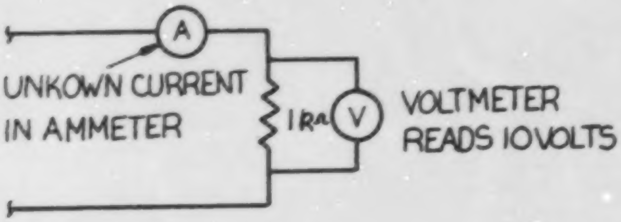
FOR CURRENT

GIVEN
E= 10 volts
R= 1000 Ω or 1k

$$I = \frac{E}{R}$$

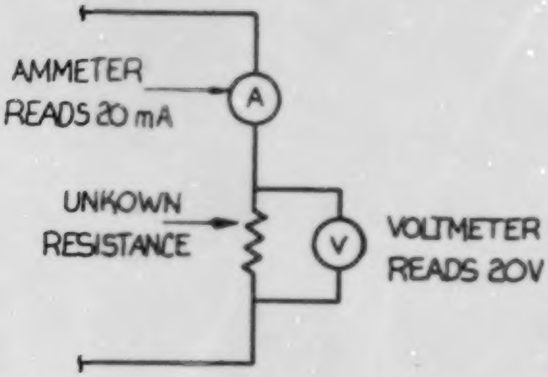
$$I = \frac{10}{1000}$$ (k ohms converted to ohms)

I = .010 amps or 10mA


A
UNKOWN CURRENT IN AMMETER
1kΩ
V
VOLTMETER READS 10VOLTS

FOR RESISTANCE

GIVEN
E= 20 volts
I= 20mA or .020A


AMMETER
READS 20 mA
A
UNKOWN
RESISTANCE
V
VOLTMETER
READS 20V

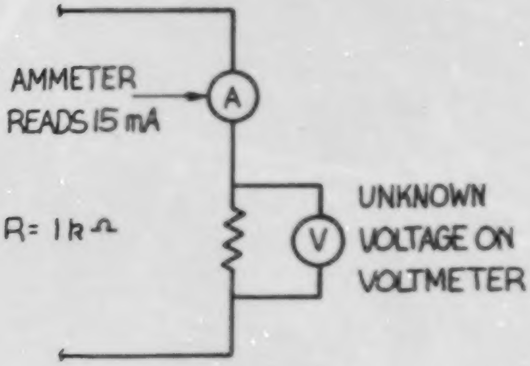
$$R = \frac{E}{I}$$

$$R = \frac{20}{.020A}$$ (20mA converted to amps)

R = .1,000 Ω or 1k

FOR VOLTAGE

GIVEN
I= 15mA or .015A
R= 1k or 1,000


AMMETER
READS 15 mA
A
R= 1k Ω
V
UNKNOWN
VOLTAGE ON
VOLTMETER

E = IR

E = .015A x 1,000

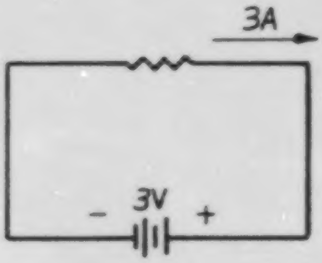
mA converted to amps

k ohms converted to ohms

E = 15 volts

To memorize the Ohm's Law equations, work out the following problems. Check by writing the equation and solving. In the following circuits the battery voltage will be the same as the voltage across the resistor.

1



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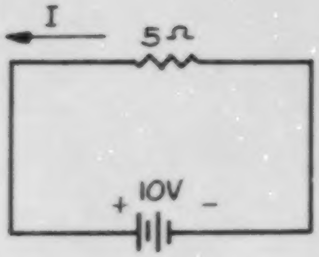
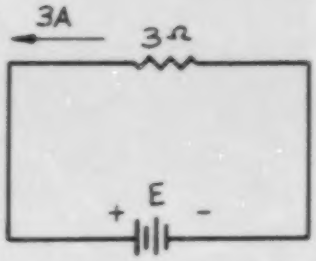


3



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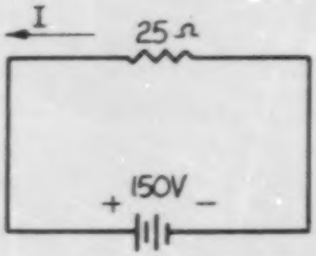
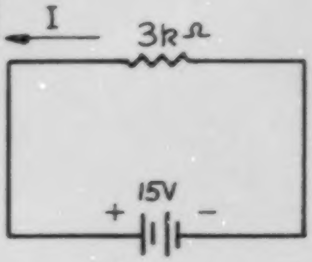


5



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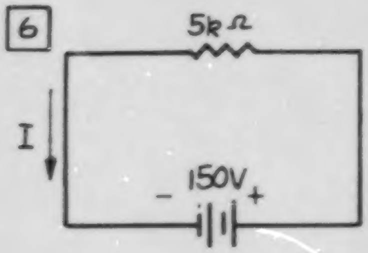

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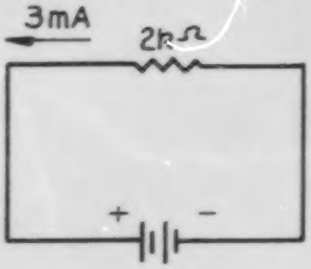

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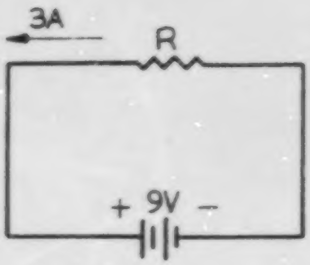
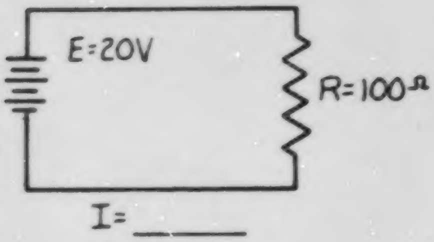


## Self-Test

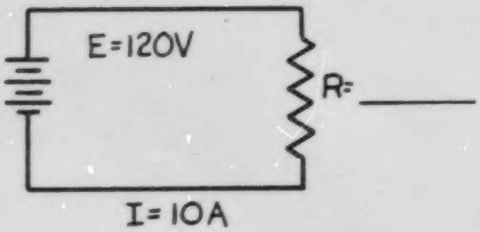
Ohm's Law Problems

1. Write the 3 formulas for Ohm's Law.

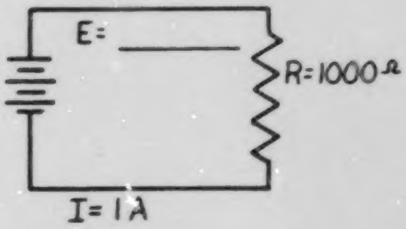
2


E=20V
R=100Ω
I=

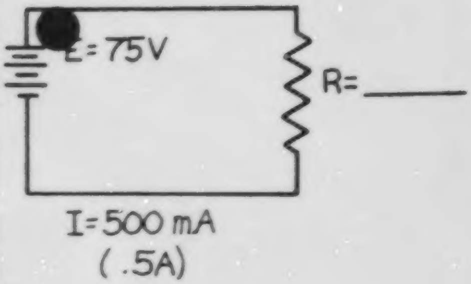
3


E=120V
R=
I=10A

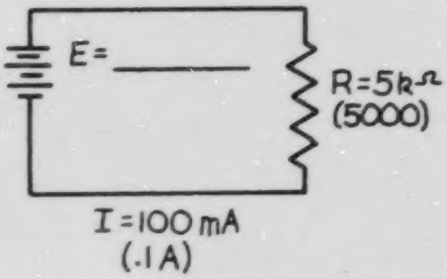
4


E=
R=1000Ω
I=1A

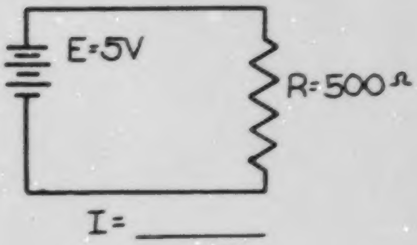
5


E=75V
R=
I=500 mA
(.5A)

6


E=
R=5kΩ
(5000)
I=100 mA
(.1A)

7

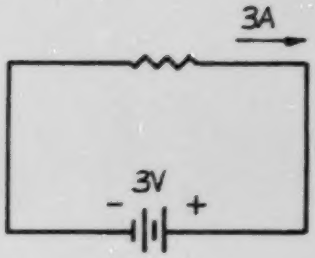


# Final Test 1

## Ohm's Law

Solve the following problems using the appropriate form of Ohm's Law for each one. The first one is done for you as an example.

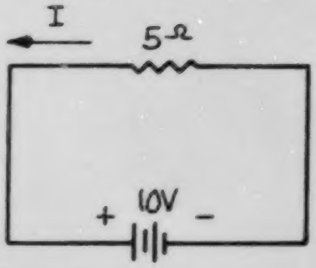
1



$R = \frac{E}{I} = \frac{3V}{3A} = 1\Omega$

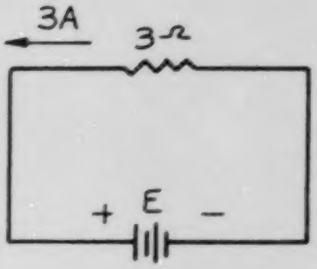
R= 1Ω

2



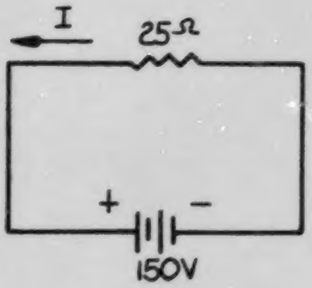
I= ______

3



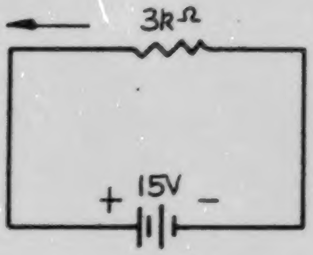
E= ______

4



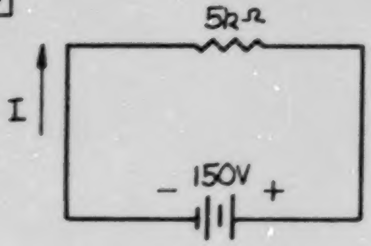
I= ______

5



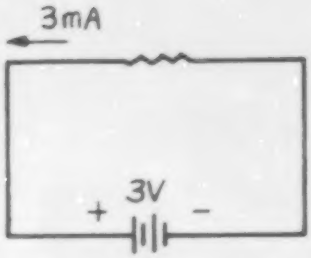
I= ______

6



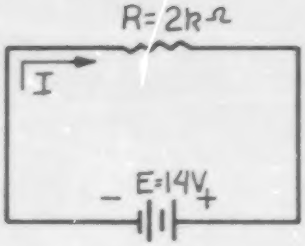
I= ______

7



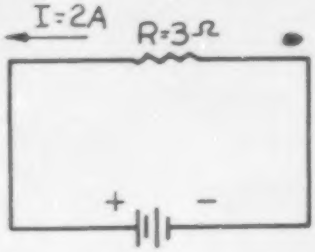
R= ______

10



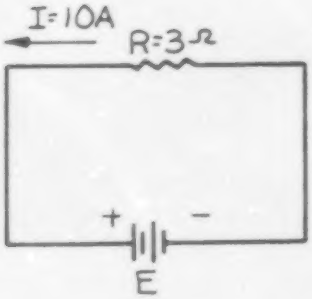
I= ______

8



E= _____

9



E= _____

Each equation tells us what will happen to our answer as each term goes up or down in value.

Refer to the illustration below:

DIRECTLY PROPORTIONAL TERM

A. $$I = \frac{E \text{ (E goes up and I goes up) (E goes down and I goes down)}}{R \text{ (R goes up and I goes down) ( R goes down and I goes up)}}$$

INVERSELY PROPORTIONAL TERM

I = Current in amps

---

B. $$E = \overset{\text{(I goes down and E goes down)(I goes up \& E goes up)}}{\underline{IR \text{ (R goes up \& E goes up)(R goes down \& E goes down)}}}$$

BOTH TERMS ARE DIRECTLY PROPORTIONAL

E = Voltage in volts

---

DIRECTLY PROPORTIONAL TERM

C. $$R = \frac{E \text{ (E goes up and R goes up) (E goes down and R goes down)}}{I \text{ (I goes up and R goes down) (I goes down and R goes up)}}$$

INVERSELY PROPORTIONAL TERM

R = Resistance in ohms.

Remember the basic way Ohm's Law was stated: The current through a resistor is directly proportional to the voltage across the resistor and inversely proportional to the resistance of the resistor. In other words when the voltage goes up, the current goes up; when the resistance goes up, the current goes down. Mathematically it looks like this:

$$I = \frac{E}{R}$$

(any term on top of the line on the right side of the equation is directly proportional to the term on the left side).

(any term on the bottom of the line is inversely proportional to the term on the left side.

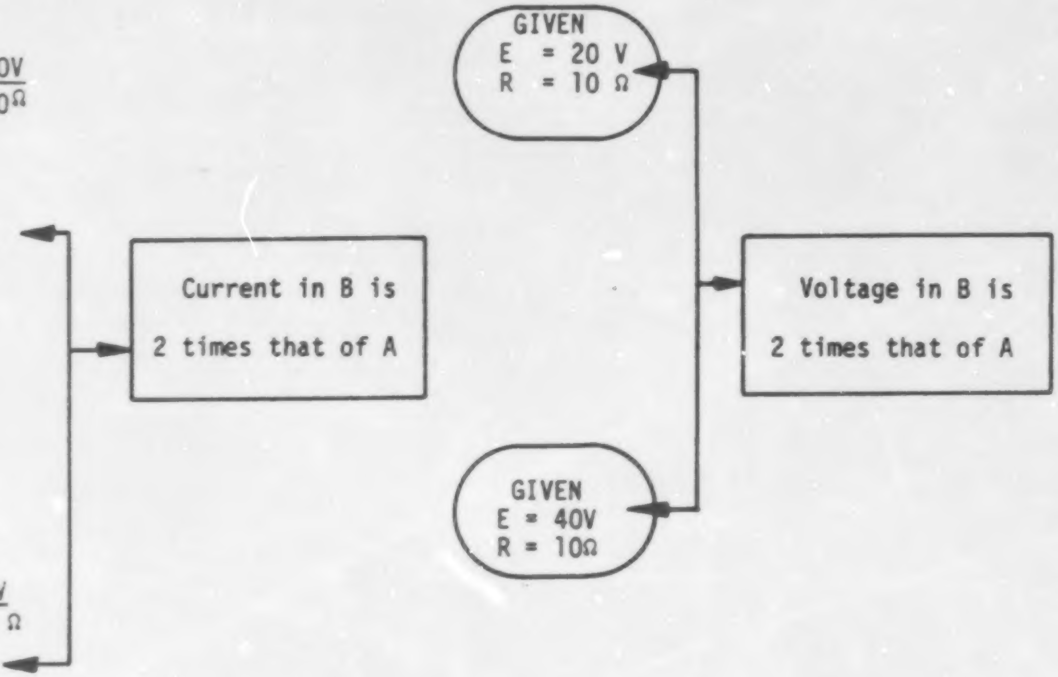
You should be able to see that, within this equation, if the voltage goes up, the current will go up. If the resistance goes up, the current will go down.

Consider the following example of direct proportion.

A. $I = \frac{E}{R}$

$I = \frac{20V}{10\Omega}$

$I = 2A$


GIVEN
E = 20 V
R = 10 Ω
Current in B is 2 times that of A
Voltage in B is 2 times that of A
GIVEN
E = 40V
R = 10Ω

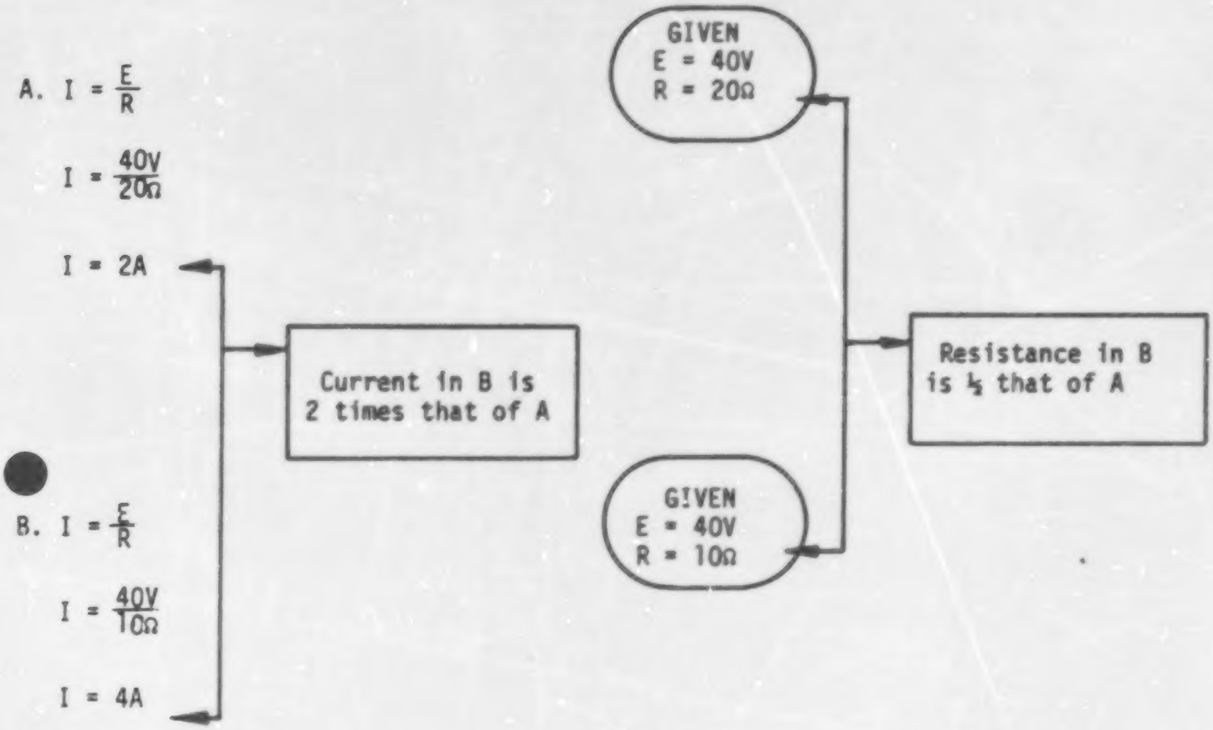
B. $I = \frac{E}{R}$

$I = \frac{40V}{10\ \Omega}$

$I = 4A$

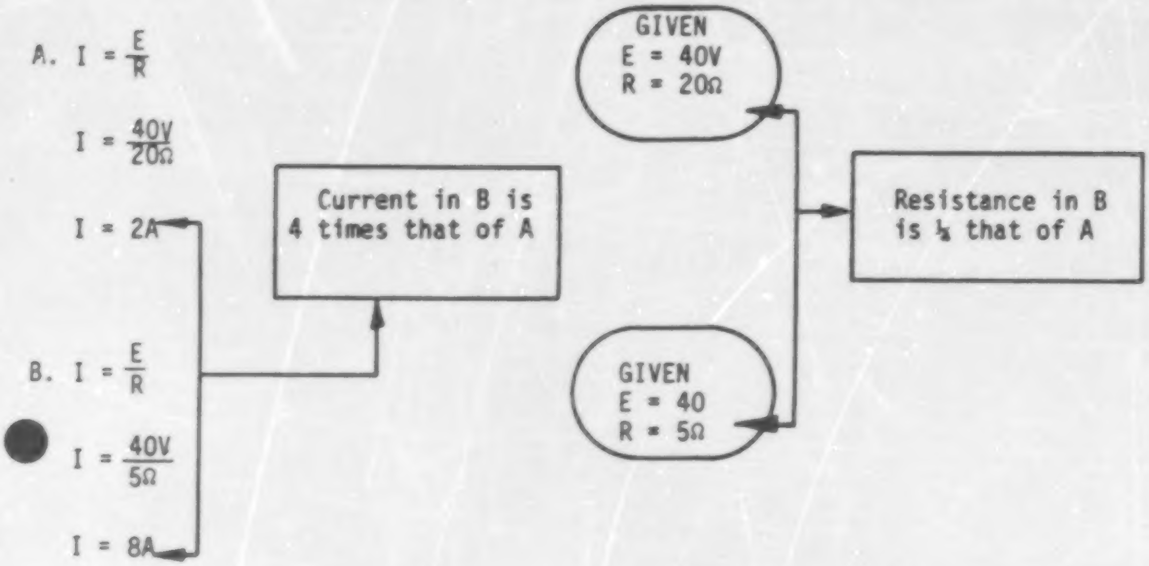
Note that when the voltage increased by 2 times, the current increased by 2 times, or by the same proportion. Therefore, we say that the voltage and the current are in direct proportion.

Next consider an example of inverse proportion.


A. $I = \frac{E}{R}$
$I = \frac{40V}{20\Omega}$
$I = 2A$
B. $I = \frac{E}{R}$
$I = \frac{40V}{10\Omega}$
$I = 4A$
Current in B is 2 times that of A
GIVEN
E = 40V
R = 20Ω
GIVEN
E = 40V
R = 10Ω
Resistance in B is ½ that of A

Note that when the resistance was cut in half (1/2), the current increased by 2 times or by the opposite proportion. Recall from your equations package that 2 is the opposite of 1/2; therefore, when the resistance was cut in half, the current doubled, or increased by an opposite or inverse proportion. The above equation shows current and resistance to be inversely proportional.

Let's consider another example of inverse proportion.


A. $I = \frac{E}{R}$
$I = \frac{40V}{20\Omega}$
$I = 2A$
B. $I = \frac{E}{R}$
$I = \frac{40V}{5\Omega}$
$I = 8A$
Current in B is 4 times that of A
GIVEN
E = 40V
R = 20Ω
GIVEN
E = 40
R = 5Ω
Resistance in B is ¼ that of A

Note that when the resistance was cut to 1/4 in B, the current in B increased by 4 times or by the opposite proportion. Recall from your equations package that 4 is the opposite of 1/4; therefore, when the resistance was cut to 1/4, the current increased by the opposite proportion of 4 times.

The two examples show that resistance and current are inversely proportional to each other. When resistance goes down, the current will always go up by the opposite proportion.

At this point, you should be familiar with the idea of direct proportion and inverse proportion. Let's look at each formula or equation for Ohm's Law and state it in spoken terms.

| | |
|---|---|
| For Current $I = \frac{E}{R}$ | The current is directly proportional to the voltage and inversely proportional to the resistance. |
| For Voltage $E = IR$ | The voltage is directly proportional to either the current or the resistance. |
| For Resistance $R = \frac{E}{I}$ | The resistance is directly proportional to the voltage and inversely proportional to the current. |

You may question why we go to all this trouble learning about the relationships of each formula. Why not just do the math indicated by each equation? The reason is that understanding Ohm's Law is necessary to succeed in applying it. At this point it would be easy to show you an equation, give you the numbers to substitute for the symbols, and let you solve for the answer. You may have to learn to do this for testing purposes to be sure you can work the problems, but it is of little value when confronted with an electronic problem in some type of radio or television receiver. Your skill in using your knowledge will be in how you analyze the problem. You must be able to interpret the voltage, resistance and current measurements that are different from that called for in a schematic diagram. This is the real test of your ability. In a later unit we will explore troubleshooting using many of the ideas presented in this learning unit.

## Self-Test

DIRECTLY PROPORTIONAL VALUES & INVERSELY PROPORTIONAL VALUES USING OHM'S LAW EQUATIONS.

1. The resistance in a circuit went down but the current stayed the same. What happened?

   a. Voltage was increased.
   b. Voltage also decreased.
   c. Voltage stayed the same.

2. If resistance stays the same and the voltage decreases, what will the current do?

   a. Increase
   b. Decrease
   c. Stay the same

3. The current in a circuit went down but the voltage stayed the same. What happened?

   a. Resistance increased.
   b. Resistance decreased.
   c. Resistance stayed the same.

4. If the current doubles through a resistor, the voltage across the resistor will

   a. remain the same.
   b. be 1/2 of the original value.
   c. be twice the original value.

5. If the resistance in a resistor doubles, the current through the resistor will

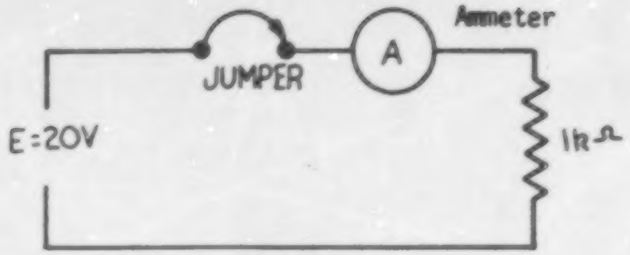
   a. double in value.
   b. be 1/2 the original value.
   c. remain the same.

## Task A

Obtain the following:

1 multimeter
1 ammeter
2 1k resistors
1 resistor of unknown value
1 circuit breadboard
1 power supply

CONSTRUCT THE FOLLOWING CIRCUIT:



STEP 1. Using Ohm's Law equation for current, solve for the current through the ammeter. (Do not apply power to this circuit.) _______ mA

STEP 2. Now apply power to the circuit and record the current measured by the meter. _______ mA

YOUR CALCULATED VALUE IN STEP 1 AND YOUR MEASURED VALUE IN STEP 2 SHOULD COME OUT THE SAME.

STEP 3. Open the jumper so no current will read on the meter. Reduce the voltage to 10 volts. 10 volts is exactly 1/2 the voltage used in Step 2. Using the rule that current and voltage are directly proportional, the current should be _____ of the value measured in Step 2. The exact amount of current should now be _____ mA.

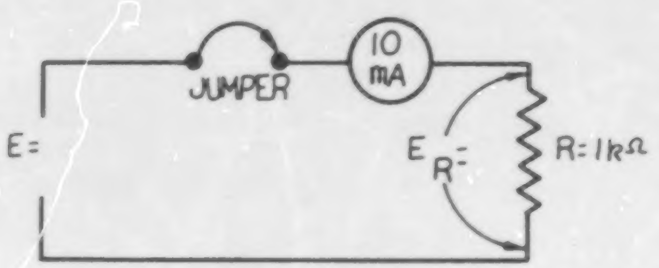
STEP 4. Connect the jumper so that the ammeter will measure current. Record the current measured by the meter, _____ mA.

THE CURRENT DECREASE MEASURED IN STEP 4 SHOULD MATCH YOUR ESTIMATIONS IN STEP 3.

STEP 5. Obtain your instructor's evaluation.

## Task B

CONSTRUCT THE FOLLOWING CIRCUIT:



STEP 1. Cover the face of the meter located on the power supply.

STEP 2. Using the Ohm's Law equation for solving for voltage, solve for the voltage across the resistor ($E_R$) and record the value. _____V

STEP 3. Starting at zero volts, turn the power supply voltage up until the ammeter reads 10mA. Measure the voltage across the 1k resistor and record the value. _____V

YOUR ANSWER FROM USING OHM'S LAW EQUATION IN STEP 2 SHOULD MATCH YOUR MEASURED VALUE IN STEP 3.

STEP 4. Remove the voltmeter from across the 1k resistor.

STEP 5. Increase the power supply voltage until the current doubles or equals 20mA.

Using the rule that current and voltage are directly proportional, the new voltage measured across the 1k resistor should increase by a factor of _____ and read _____ volts.

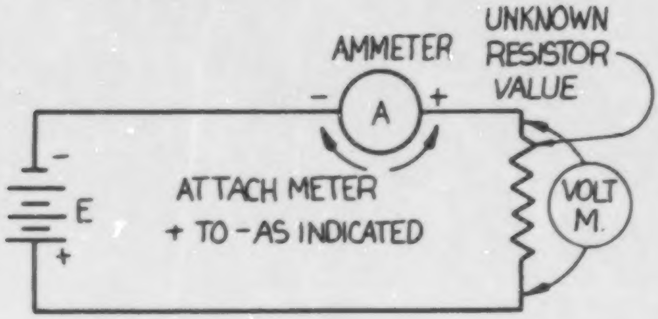
STEP 6. Attach the voltmeter across the 1k resistor and measure the new voltage. _____V

YOUR ESTIMATE IN STEP 5 SHOULD MATCH YOUR MEASURED VALUE IN STEP 6.

STEP 7. Obtain your instructor's evaluation.

# Task C

CONSTRUCT THE FOLLOWING CIRCUIT:



STEP 1. Have your instructor cover the color code on a resistor by using masking tape.

STEP 2. Install the resistor as indicated in the above diagram.

STEP 3. Starting with the voltage at zero, increase the voltage until the ammeter reads 10mA.

STEP 4. Measure and record the voltage across the unknown resistor. _____V

STEP 5. Using Ohm's Law, calculate the value of the resistor using the 10mA current and the voltage you measured in Step 4.

STEP 6. Remove the resistor from the circuit.

STEP 7. Using your multimeter, set to read resistance, measure and record the value of the unknown resistor. _____Ohms

YOUR CALCULATED VALUE FROM STEP 5 SHOULD MATCH YOUR MEASURED VALUE IN STEP 7.

STEP 8. Obtain your instructor's evaluation.

# Final Test 2

1. The resistance in a circuit went up but the current stayed the same. What happened?

   A. Voltage was increased.
   B. Voltage was decreased.
   C. Voltage stayed the same.

2. If the resistance stays the same and the voltage increases, what will the current do?

   A. Increase.
   B. Decrease.
   C. Stay the same.

3. The current in a circuit went up but the voltage stayed the same. What happened?

   A. Resistance increased.
   B. Resistance decreased.
   C. Resistance stayed the same.

4. If the current through a resistor increases 3 times, the voltage across the resistor will

   A. remain the same.
   B. be 1/3 of the original value.
   C. be three (3) times the original value.

5. If the resistance in a resistor decreased by 1/2, the current through the resistor will

   A. double (X2) in value.
   B. be 1/2 of the original value.
   C. remain the same.

# Final Evaluation

| | OK | Re Do |
|---|---|---|
| Completed the Task on Ohm's Law for current | | |
| Completed the Task on Ohn's Law for voltage | | |
| Completed the Task on Ohm's Law for resistance | | |
| Completed final Test I on Ohm's Law problems with 80% accuracy. | | |
| Completed Final Test II on Ohm's Law relationships with 80% accuracy. | | |

When all checks indicate OK, proceed to the next learning package.

# Answers

## Answers to Exercise #1

1. $R = \frac{E}{I} = \frac{3V}{3A}\ 1\Omega$

2. $I = \frac{E}{R} = \frac{10}{5\Omega} = 2A$

3. $E = IR = 3A \times 3\Omega = 9V$

4. $I = \frac{E}{R} = \frac{150V}{25\Omega} = 6A$

5. $I = \frac{E}{R} = \frac{15}{3{,}000\Omega} = .005 = .005A$ or 5mA

6. $I = \frac{E}{R} = \frac{150V}{5{,}000} = .03A$ or 30mA

7. $E = IR = .003A \times 2{,}000\Omega = 6V$

8. $R = \frac{E}{I} = \frac{9V}{3A} = 3\Omega$

## Answers to Self-Test #1

1. $I = \frac{E}{R}$ $\quad R = \frac{E}{I}$ $\quad E = IR$

Any order is correct as long as the equation is written correctly.

2. $I = \frac{E}{R}$ $\quad I = \frac{20V}{100\Omega}$ $\quad I = .2A$ or 200 mA

3. $R = \frac{E}{I}$ $\quad R = \frac{120V}{10A}$ $\quad R = 12\Omega$

4. $E = 0 \times R$; $E = 1 \times 1{,}000\,\Omega$; $E = 1{,}000V$ or 1kV

5. $R = \frac{E}{I}$ $\quad R = \frac{75V}{.5A}$ $\quad R = 150\Omega$

6. $E = IR$ $\quad E = .1A \times 5{,}000\Omega$ $\quad E = 500V$

7. $I = \frac{E}{R}$ $\quad I = \frac{5V}{500\Omega}$ $\quad I = 10mA$ or .010A

## Answers

### Answers to Self-Test #2

1. B. $R = \frac{E}{I}$ Restance and voltage are terms that are directly proportional. Therefore, if the resistance goes down, the voltage would have to go down.

2. B. $I = \frac{E}{R}$ Current and voltage are terms that are directly proportional. Therefore, if the voltage decreases, the current would have to decrease.

3. A. $R = \frac{E}{I}$ Current and resistance are inversely proportional terms. Therefore, if the current goes down, the resistance would have to go up or increase.

4. C. $E = I \times R$ In this equation, current and resistance are terms that are directly proportional. Therefore, if the current doubles, the voltage will double, or be twice the original value.

5. B. $I = \frac{E}{R}$ This equation shows current and resistance to be inversely proportional. Therefore, doubling the resistance (X2) will have the opposite effect on the current, and it will be 1/2 of its value (opposite of 2 is 1/2).

INSTRUCTIONAL LEARNING SYSTEMS

# 2.9

## POWER AND WATT'S LAW

## Goal:

The apprentice will be able to use Watt's Law in computing problems in electrical power.

## Performance Indicators:

1. Compute wattage from given voltage and amperage.
2. Compute amperage from given wattage and voltage.
3. Compute voltage from given amperage and wattage.

# BASIC ELECTRONICS

# Power and Watt's Law
## EL-BE-16

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| Resistors of different wattage and equipment to perform a task. | Perform an experiment demonstrating P, I, and E relationships using Watt's Law. |
| Watt's Law | Answer a set of test questions with 80 percent accuracy. |

## Directions

Obtain the following material:

Circuit Board
Power Supply
Multimeter

10 ohm 1/4 watt resistor

10 ohm 1 watt resistor

## Learning Activities

______ Study Key Words list.

______ Read Information Sheet.

______ Do Self-Test on Watt's Law equations.

______ Do Task on Power.

______ Do Final Test on Watt's Law.

______ Obtain Final Evaluation.

## Key Words

Power: Work done by electrical pressure or voltage.

Watt: The basic unit of power.

Watt-hour: The basic unit of power multiplied by time.

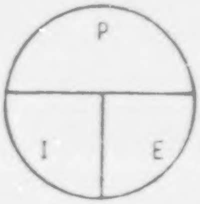
Wattage: The amount of power in watts used to do work by an electrical device.

Watt's Law: P = I X E

Amphour: The amount of current per hour available in a battery.

Power Dissipation: The amount of heat generated in watts by an electrical device doing work.

Watt's Law Pie:



A memory aid to learning Watt's Law.

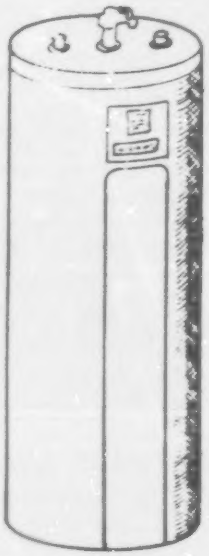
Dissipate: To give off energy in the form of heat.

BEST COPY AVAILABLE

The basic unit of power is the watt. All of the items that you have in your home that use electricity will tell you how much power they use by telling you how many watts they use.

Approximate Cost of Operation of Applicances

| Appliance | Average Wattage | Est. Cost per Month at $0.04 Per KWH |
|---|---|---|
| Toothbrush | 1.1 | .003 |
| Clock | 2 | .06 |
| Hair Dryer | 381 | .05 |
| Sewing Machine | 75 | .04 |
| Shaver | 15 | .04 |
| Toaster | 1146 | .13 |
| Vacuum Cleaner | 630 | .15 |
| Radio | 71 | .29 |
| Washing Machine | 512 | .34 |
| Coffee Maker | 894 | .35 |
| TV, B & W | 45 | .33 |
| TV, Color | 145 | 1.06 |
| Dishwasher | 1201 | 1.21 |
| Refrigerator/ Freezer Manual Defrost | - | 2.33 |
| Clothes Dryer | 4856 | 3.31 |
| Range with oven | 12,200 | 3.92 |
| Refrigerator/ Freezer Auto Defrost | - | 5.98 |
| Water Heater | 4474 | 14.91 |
| Central A/C | 1670/ton | 35.00 |



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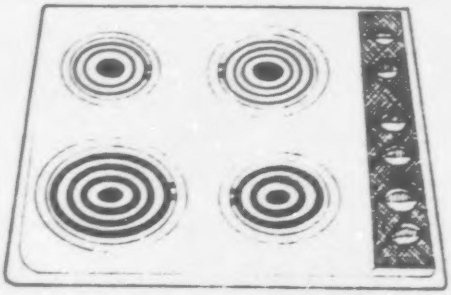
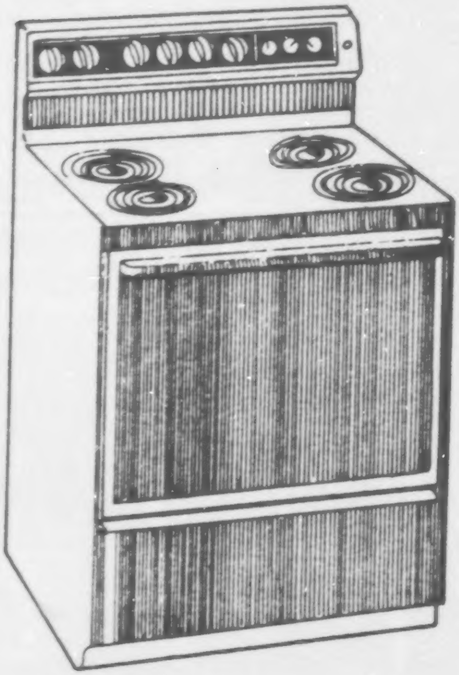
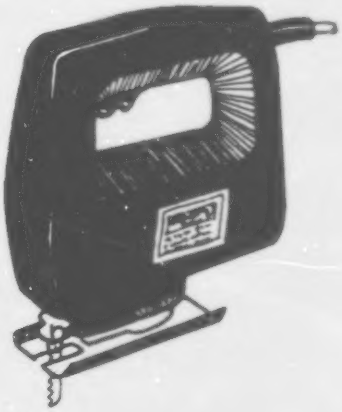
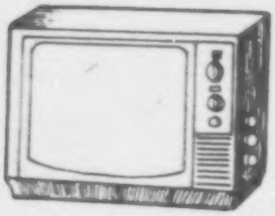


# Information Sheet

You will often hear the words "alternate sources of energy" when describing different sources of electricity. Nuclear energy, solar energy, geothermal energy, and wind power come from different sources. The energy from all these different sources can be used to create electrical pressure or electricity. When this electrical pressure does some work for us, such as light a lamp or run a TV set we are using some of the energy. The amount of energy we use will depend on the type of work being done by our electrical pressure. In this unit we are not concerned with the energy itself but with the work that is being done. Power is the word used to describe the ability of this electrical pressure to do work. Anytime electricity is used to do something, power is also being used. The amount of power used depends upon what type of electrical appliance you are using.







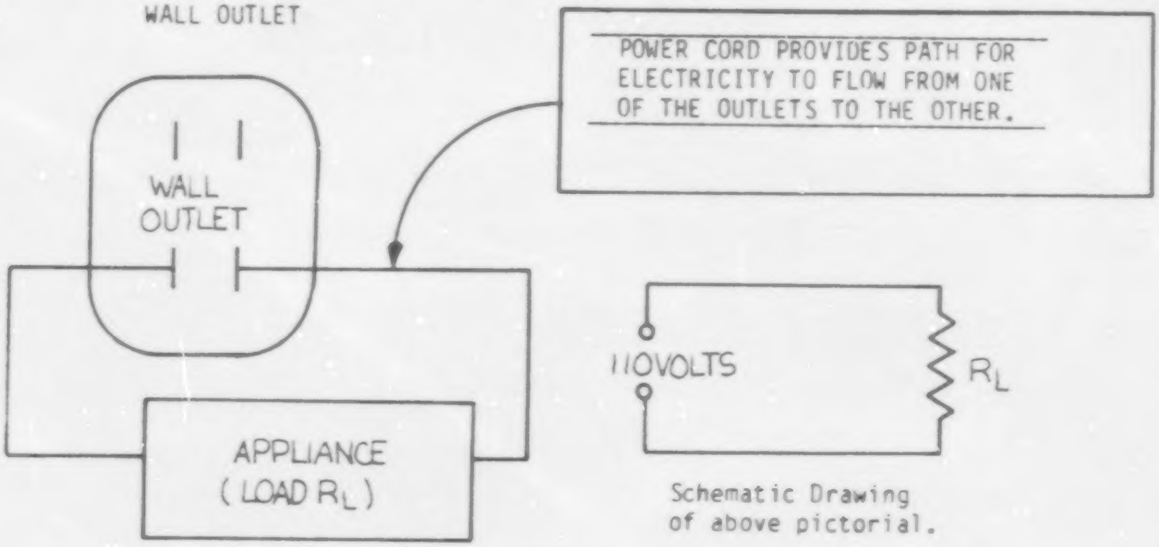
A stove, for example, uses more power than a TV set. The two electrical devices in your home that use the most power are the hot water heater and electric heater. The size of the bill that the electric company sends you depends on how much power you use. Conserving the amount of power you use can prove very helpful in trying to keep the electric bill as low as possible. If you have ever looked at your electric bill and tried to figure out what makes it so high, you may have noticed that you were billed for the amount of watt-hours used. The amount of watts used times the time in hours the power is used is called watt-hours.

The clearest example of the relationship of wattage used to work done is the light bulb. You are aware that a 100 watt bulb gives much more light than a 40 watt bulb and requires much more electricity to produce that light. Most home light bulbs range from 25 to 150 watts. The electric appliances that you have will average from 100 watts to several thousand watts. Your electric company will charge you for the amount of watt-hours used. Since you are billed only once per month, several thousand watt-hours will be on your bill each month.

To figure out how many watt-hours something will use, simply multiply the amount of power in watts the appliance uses by how many hours it is turned on. For example, if you leave a 100 watt light bulb on for 30 days or 720 hours, you would use 100 x 720 or 72,000 watt-hours. This would normally be expressed as 72 kilowatt-hours or 72 kwh.

The electric company charges a fixed amount for each kilowatt-hour used. The electric lines usually supply 120 volts for small appliances and 240 volts for larger appliances. If you do not have a device connected to the electrical outlet and the device turned on, then you are not using any electrical power or energy. It is only when the item is plugged in and turned on that energy or power in watts is being used.

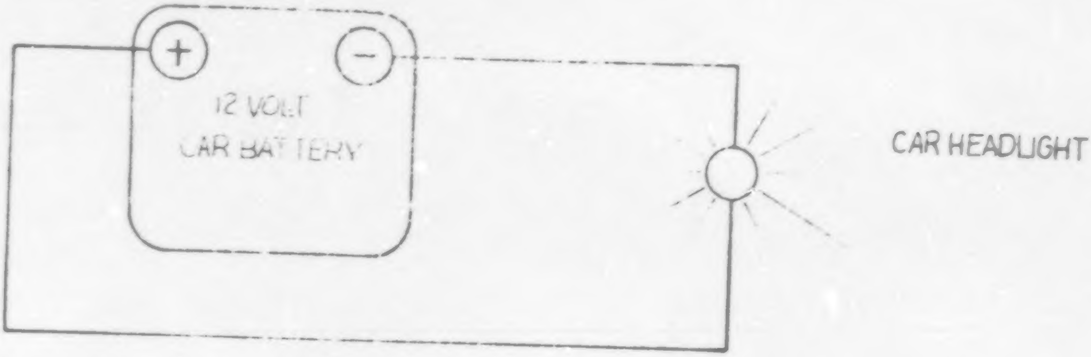
Power is used anytime you have a conductor which connects one slot of the electrical outlet to the other. The conductor forms a pathway for the electricity. The appliance or the electronic device which is plugged into the wall represents a LOAD on the electrical service to the house. Loads are often represented in schematic diagrams as a resistor and often indicated as $R_L$.


WALL OUTLET
POWER CORD PROVIDES PATH FOR ELECTRICITY TO FLOW FROM ONE OF THE OUTLETS TO THE OTHER.
WALL OUTLET
APPLIANCE (LOAD $R_L$)
110VOLTS
$R_L$

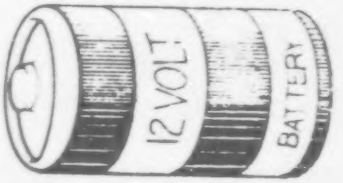
Schematic Drawing of above pictorial.

Power is also used if you provide a connecting path between the two terminals of a battery, even if there is no load. The battery will go dead almost immediately if there is no load to limit the flow of current. This is known as a short circuit.

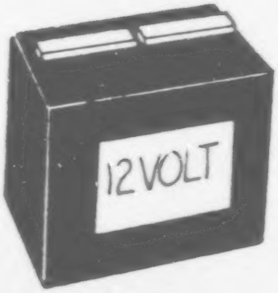
The load parts of the electrical system in a car, such as headlights, radio, starter, provide a resistance to the flow which limits the current drain from the battery. The load also dissipates heat and light which prevents the wires from burning up.



The amount of power that a battery can supply is much less than the amount of power that can be supplied by the electrical lines in your home. The amount of power that a battery can supply usually depends on the size and type of the battery.



SMALL AMOUNT OF POWER

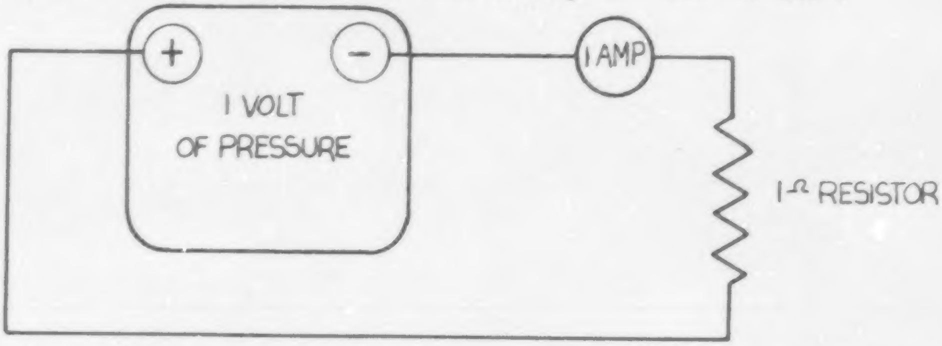


LARGE AMOUNT OF POWER

The amount of voltage that the battery provides is not the only factor we must consider. The 12 volt flashlight battery and the 12 volt car battery each provide 12 volts at the terminals. The flashlight battery could never be used to start a car because it cannot supply the amount of power required by the car starter.

You may have experienced a "dead battery" in a car that would not supply enough power to start the car but would still cause the headlights to light up. That happened because the starter requires much more power than the headlights. When the battery gets weak, it cannot supply large amounts of power, but it still may be able to supply a small amount of power.

Devices that get their power from a battery or power supply such as that used in your experiments state their power requirements in AMPS instead of WATTS. To find out how many watts are required by a device that tells you how much current in amps it requires will involve some calculations. Determining watts needed (or power) is the basic function of Watt's Law. Electrical devices that plug into the wall outlet will always have the power in watts that they require printed somewhere on the device. All other products that use power from some type of battery or power supply usually tell you how much current in amps they require. How to convert amps into watts involves an equation known as Watt's Law. The law states that 1 watt of power is used when 1 volt of electricity causes 1 amp of electrical current to flow through a 1 ohm resistor.

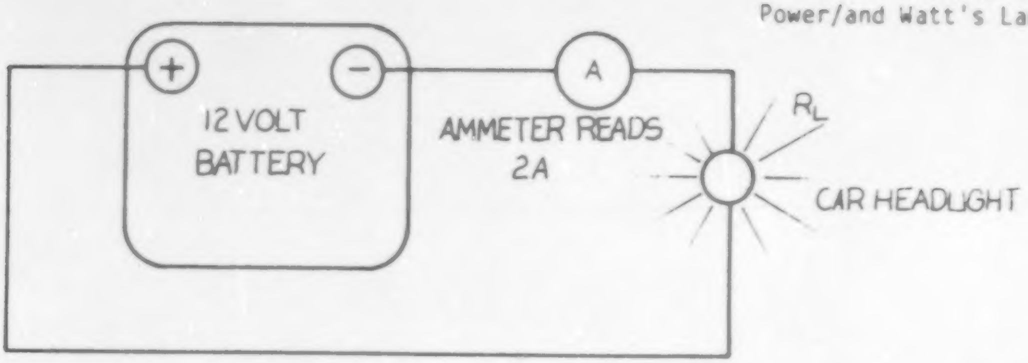


Watt's Law is usually expressed in an equation that uses voltage and current. The equation for Watt's Law using voltage and current looks like this:

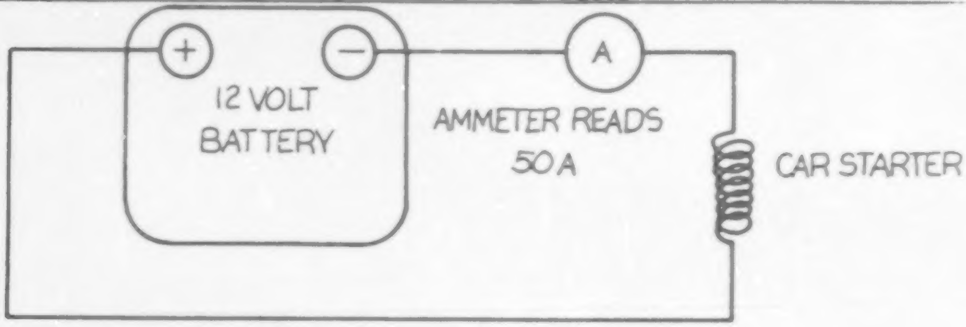
$$P = I \times E$$

| POWER in watts | EQUALS | CURRENT in amps | TIMES | VOLTAGE in volts |
|---|---|---|---|---|
| 1 watt | equals | 1 amp | times | 1 volt |

Let's go back to the problem of figuring out how much power your headlights or car starter may require from the battery. Due to the load resistance inside the headlight, 2 amps of current may flow when connected to a 12 volt battery. The car starter may represent a lower load resistance so that 50 amps of current may flow when connected to the 12 volt battery. Since we know the current through each load and the voltage across each load, we can compute the amount of power needed for each device.



P = I X E    P = 2A X 12 V    P = 24 watts



P = I X E    P = 50A X 12 V    P = 600 watts

From the equation P = I X E, you should recognize that all the terms are directly proportional. This means that if the value of the current or voltage increases, the power will also increase. The opposite is also true. If either the current or the voltage decreases, then the power used by the item will also decrease. Most electrical items require a certain voltage to operate properly so it is not practical to reduce the voltage to lower the power required. A new small 12 volt lantern battery may be able to supply only 1/2 amp for 1 hour. This means it has a rating of 1/2 ampere-hour. If we apply our Watt's Law using P = I X E, we can come up with how many watts it can supply. P = 1/2 amp X 12 volts = 6 watts. Let's try the same thing with a car battery rated at 50 amp-hr. 50 amp-hr means it can supply 50 amps for 1 hour. P = I X E or P = 50A x 12 v = 600 watts. The total amount of energy the lantern battery can supply is 6 watts X 1 hour or 6 watt-hours, but the total amount of energy the car battery can supply is 600 watts X 1 hour or 600 watt-hours.

As you can see from the examples above, the smaller battery cannot supply very much energy, only 6 watt-hours. The larger car battery can supply 600 watt-hours. Since they are both rated as providing 12 volts, you should recognize that it is not how much voltage they provide but how much power and energy they can supply that makes the difference.

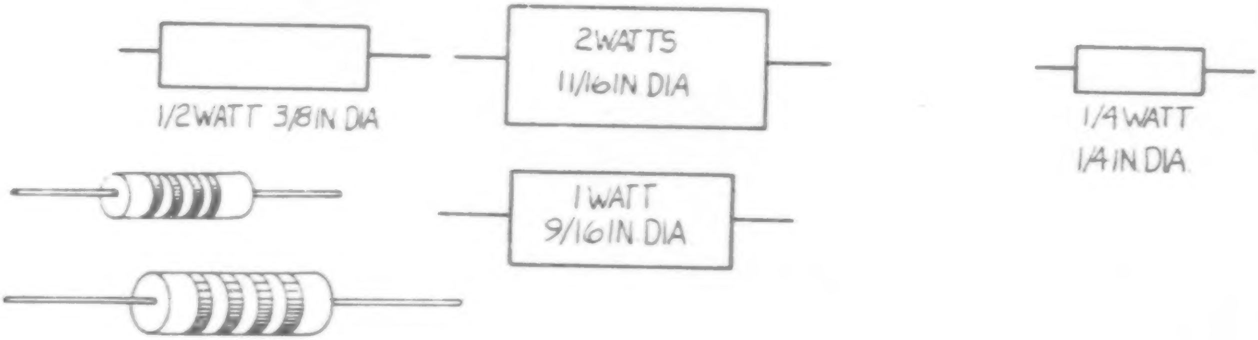
The type of power we have discussed so far has dealt with the amount of power required to do a certain work in a certain time: the car battery to turn the starter or light the headlight, the 110 volt wall plug to run a household appliance. The word power can also be used to express the amount of heat generated in an electrical item. Consider your electric stove or electric heater. Both of these devices are designed to give off heat.

Other items such as radios or televisions we do not want to get too hot as heat quickly damages the parts. When power is used to do some kind of electrical work, heat is always generated by the work being done. An example of heat being produced by the work being done is the light bulb. The light bulb is principally designed to give off light. But if you touch the bulb after it has been on for a while, you will feel a great deal of heat coming from the light bulb. If you leave your hand on the bulb for longer than a second, you will probably get burned. Larger wattage light bulbs which give off more light will also give off more heat. From this example, you can see that the power required by the light bulb is used in two different ways:

1. The power that produces the light.
2. The power that produces the heat.

Both of these powers are additive and the total amount of power required by the light bulb is the sum of the power used in heat and the power used for the light.

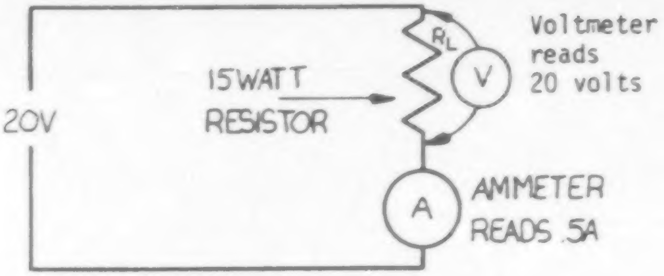
Keeping parts from being destroyed by the heat dissipated in doing work in a radio or television receiver is of major importance to the technician. To assist us in selecting parts that will not overheat or burn up, the parts manufacturers will many times give us the amount of power in watts that the part can dissipate or throw off in the form of heat. More than that amount will damage the part. Resistors are an example of this. Remember from your study unit on resistors that they come in various wattage sizes: 1/4 watt, 1/2 watt, 1 watt, 2 watts, etc.



Basically, the bigger the part is the more heat it can safely dissipate. This is true for almost all electronic parts. Remember our power equation P = I X E tells us that the amount of power used to do work and dissipate heat in our electronic circuit is directly proportional to the voltage and current. If either the current or voltage increases due to a short (a decrease in resistance) in our circuit, the power will also increase. If the increase in power is above the power rating of the part, it will probably burn up.

Consider the two examples below:

A.

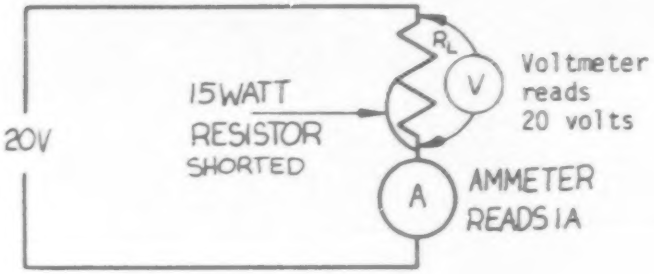

R_L
Voltmeter reads 20 volts
V
15 WATT RESISTOR
20V
A
AMMETER READS .5A

$P = I \times E$

$P = 20V \times .5A$

$P = 10$ watts

B.


R_L
Voltmeter reads 20 volts
V
15 WATT RESISTOR SHORTED
20V
A
AMMETER READS 1A

$P = I \times E$

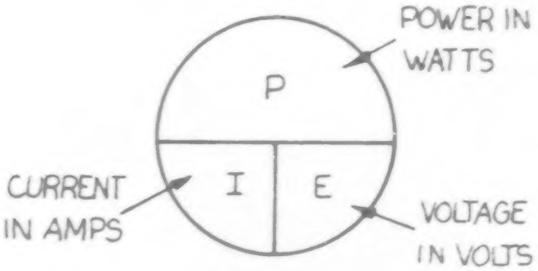
$P = 20V = 1A$

$P = 20$ watts

In example A, 10 watts is consumed by the resistor. Since the resistor is rated at 15 watts, it will not burn up, although if you touch it you will feel some heat. In example B, the current has increased to 1 amp and the power increased to 20 watts. That same resistor rated at 15 watts now has 20 watts consumed in it and it will probably burn up.

Anytime you find a resistor burned up in a circuit, you should carefully check the circuit to be sure there is no short which would cause excessive current to flow. Remember, a short means that the resistance has decreased to a low value. From Ohm's Law, a decrease in resistance would mean an increase in current. It is this increase in current that would increase the power consumed by the part.

To memorize Watt's Law and all of its variables, we can use an aid similar to the aid used to memorize Ohm's Law. The Watt's Law memory aid is also called a PIE. (Since P = I X E, this is usually an easier equation to remember.)


POWER IN WATTS
P
I
E
CURRENT IN AMPS
VOLTAGE IN VOLTS

You can use the Watt's Law PIE just like you used the Ohm's Law PIE:

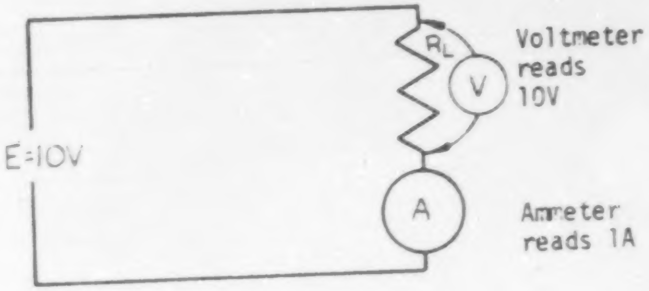
To find the power, simply put your finger over the letter P and you get $P = I \times E$.

To find the voltage, simply put your finger over the letter E and you get $E = \frac{P}{I}$.

To find the current, simply put your finger over the letter I and you get $I = \frac{P}{E}$.

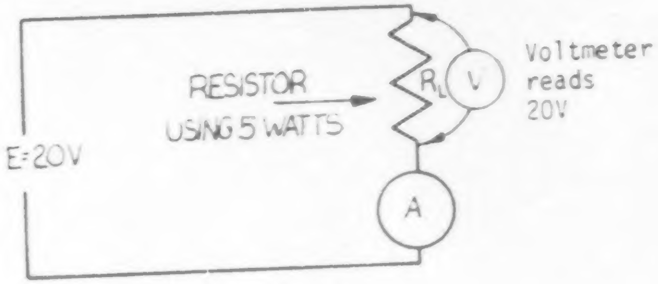
Let's try some example problems for each equation. Remember you must know two of the three terms to solve for the third.

Example A: To find the power when the voltage and current are known
Equation $P = I \times E$


$R_L$
V
Voltmeter reads 10V
E=10V
A
Ammeter reads 1A

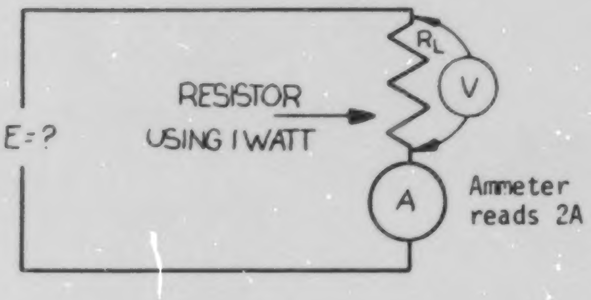
$$P = E \times I$$
$$P = 10 \times 1$$
$$P = 10 \text{ watts}$$

Example B: To find the current when the voltage and power are known.
Equation $I = \frac{P}{E}$


RESISTOR USING 5 WATTS
$R_L$
V
Voltmeter reads 20V
E=20V
A

$$I = \frac{P}{E}$$
$$I = \frac{5}{20}$$
$$I = .25 \text{ amps}$$

Example C: To find the voltage when the current and power are known.
Equation $E = \frac{P}{I}$


E=?
RESISTOR
USING 1 WATT
$R_L$
V
A
Ammeter
reads 2A

$E = \frac{P}{I}$

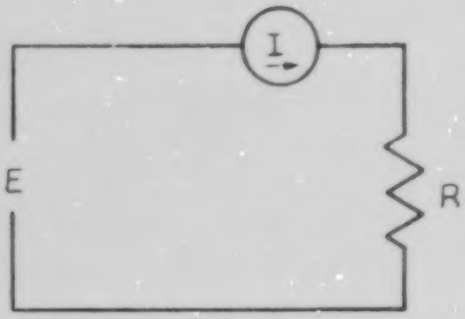
$E = \frac{1}{2}$

$E = .5$ Volts

Occasionally you will work with products that have a horsepower rating. One horsepower (Hp) is equal to 746 watts. All power equations apply to horsepower ratings in watts, the same as any other wattage rating.

## Self-Test

This basic circuit is used for all of the practice problems



You may refer to the Information Sheets for any equations.

1. P =
   I = 2 A
   E = 3 V

2. P =
   I = .5 A
   E = 12 V

3. P = .5 W
   I = 2 A
   E =

4. P = 1 W
   I = .001
   E =

5. P = 2 W
   I =
   E = 50 V

6. P = .25 W
   I =
   E = 5 V

7. P = 10 W
   I = 2 A
   E =

8. P =
   I = .05
   E = 10 V

9. P = .5 W
   I = 5 mA
   E =

10. P =
    I = 20 mA
    E = 20 V

11. P = .25 W
    I = 125 mA
    E =

12. P = 10 W
    I = 50 mA
    E =

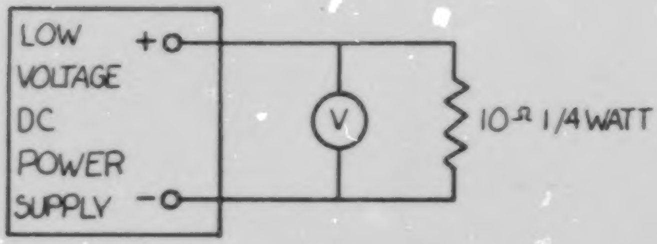
# Task

Materials required:

1. Low-voltage power supply
2. Two resistors, 1/4 watt 10 Ω, 1 watt 10 Ω
3. Voltmeter 0-30 VDC

Procedure:

Step 1. Connect the circuit as shown below using the 1/4 watt resistor. CAUTION: Power "OFF" and observe polarities.



Step 2. With the voltage control at minimum, turn the power switch to "ON" and slowly raise the applied voltage until the resistor begins to get warm. Let the resistor operate at this maximum condition for several minutes while you note the maximum operating condition of a 1/4 watt resistor. Carefully touch the resistor with your finger to note its temperature.

Step 3. Raise the applied voltage slowly until the resistor heats and burns open. Note and record the value of the applied voltage when this happens. NOTE: When the resistor has opened there will no longer be a current path, current will no longer flow, and the resistor will have infinite resistance.

Applied voltage when resistor opened: ______________________________

Step 4. Compute and record the amount of power that the resistor was dissipating at the time it opened.

Power dissipation at time of failure: ______________________________

Step 5. Reconnect the circuit using a 10 Ω 1 watt resistor.

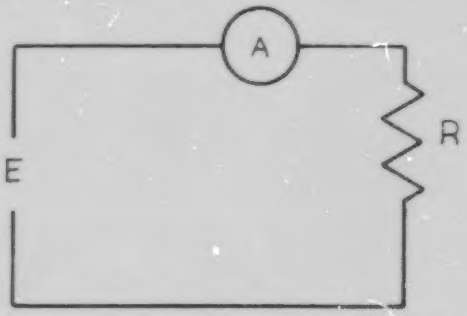
Step 6. Apply the same voltage which destroyed the 1/4 watt resistor in Step 4, noting the operating temperature of the higher wattage resistor.

Step 7. How does the operating temperature of the resistors in Step 2 and 6 compare?

Step 8. Obtain the instructor's evaluation.

# Final Test

The following questions refer to this circuit.



1. P = 2 W
I = 1 mA
E =

2. P = 2 W
I = .05 A
E =

3. P = 20 W
I = .5 A
E =

4. P = .25 W
I =
E = 250 V

5. P =
I = 50 mA
E = 500 V

6. P = .25 W
I = 2 mA
E =

7. A 115 V electric heater furnishes 1150 W of heat. What is the operating current?

a. 1.0 A b. 1.150 A c. 10 A

8. What current does the average 115 V 100 W light bulb draw?

a. .087 A b. .87 A c. 1500 A

# Final Evaluation

Date ____________

Name ____________

| | OK | REDO |
|---|---|---|
| Accurately completed a task demonstrating P, I, and E relationships | ____ | ____ |
| Answered questions on a Final Test with 80% accuracy | ____ | ____ |

## Answers

Self-Test Answers

1. 6 W
2. 6 W
3. .25 V
4. 1000 V or 1 kV
5. .04 A or 40 mA
6. .05 A or 50 mA
7. 5 V
8. .5 W
9. 100 V
10. .4 W
11. 2 V
12. 200 V

iLS

INSTRUCTIONAL LEARNING SYSTEMS

# 2.10

## KIRCHOFF'S CURRENT LAW

### Goal:

The apprentice will be able to use Kirchoff's Law in computing current values of electrical circuits.

### Performance Indicators:

1. Describe Kirchoff's Current Law.
2. Describe algebraic sums.
3. Solve for current through resistors.

# BASIC ELECTRONICS

# Kirchhoff's Current Law
## EL-BE-18

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| Resistors of different values | Apply Kirchhoff's Law for current in a simple circuit with one voltage source. |
| A multimeter | |
| A circuit breadboard for constructing simple circuits | Solve for an unknown current using Kirchhoff's Current Law. |
| A power supply | Complete a Final Test with an accuracy of 80%. |
| A Final Test on Kirchhoff's Current Law | |

## Directions

Obtain the following material:

1000 ohm resistor
20,000 ohm resistor
10,000 ohm resistor
Circuit breadboard
Power supply capable of providing 0-30 volts
Multimeter capable of measuring currents 0-300mA

## Learning Activities

______ Study the Key Words list.

______ Read the Information Sheets.

______ Do the Self-Test.

______ Do the Task for Kirchhoff's Current Law.

______ Do the Final Test.

______ Obtain Final Evaluation.

## Key Words

Kirchhoff's Current Law: "The algebraic sum of the currents entering any point and leaving any point must equal zero."

Algebraic Sum: The result of adding positive and/or negative numbers. In electrical circuits:

A. Currents entering a point are assigned a positive value (+).
B. Currents leaving a point are assigned a negative value (-).

$I_R$: Symbol which represents current flow through a resistor (notice the 'R' is written in a lower position); i.e.,

$I_{R_1}$ = current flowing through resistor $R_1$

$I_{R_2}$ = current flowing through resistor $R_2$

R: Symbol which specifies a certain resistor; i.e.,

$R_1$ = resistor number 1 in the circuit

$R_2$ = resistor number 2 in the circuit

$R_3$ = resistor number 3 in the circuit

# Information Sheet

## About Kirchhoff's Laws

Kirchhoff's Laws are very useful in learning to work on electronic products. The usefulness results from a common-sense understanding of the laws and not just being able to work out problems. Simply stated, Kirchhoff's Laws say that you cannot get more voltage or current out of a circuit than you put into it.

Assume that you are measuring a DC voltage of about 50 volts in a circuit that operated from a 25 volt supply. An "error light" should come on in your mind saying, "Hey, if I only started out with 25 volts, then that's the most I can measure so my reading of 50 volts must be incorrect."

A similar condition could occur while making a current measurement. If you are measuring 75 milliamps in part of a circuit that has a total supply current of only 50 milliamps, then again the light should come on and say, "Hey, if the whole circuit only draws 50 milliamps, then that is the most that can be measured."

The unlikely readings you may obtain for the two examples above should tell you to recheck your instrument readings or further examine the circuit for possible shorts. (Shorts, or less resistance, create more current.)

Kirchhoff's Laws keep us on track by reminding us that the maximum values we can measure will depend on the maximum voltage and current supplying our circuit.

These next two learning packages will make you familiar with two of the more popular aspects of Kirchhoff's Laws: one package, Kirchhoff's Law for current, and one package, Kirchhoff's Law for voltage using one voltage supply.

## Kirchhoff's Current Law for One Voltage Source

Kirchhoff's Law for current can be stated technically: "The algebraic sum of the currents entering any point and leaving any point in a circuit must equal zero." Let's try to restate the law in plain language. "The total current entering a circuit must be equal to the total amount of current leaving the circuit." Study the illustration on the following page.

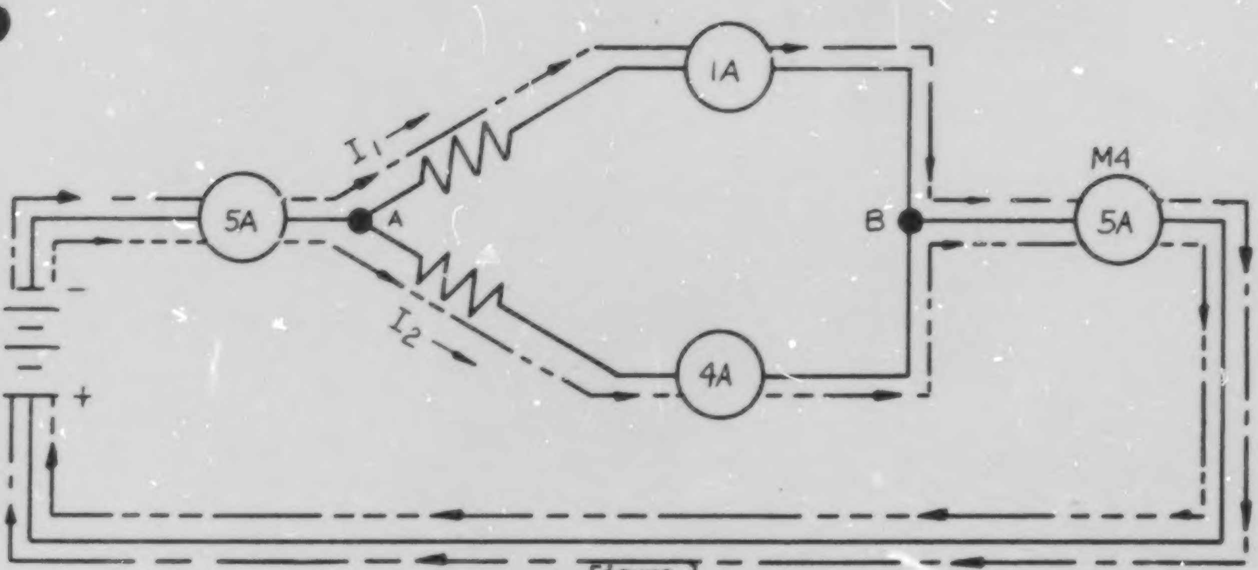


Figure 1

The term "algebraic sum" in the original technical explanation refers to adding positive and negative numbers. By marking the currents entering our circuit "positive values" and marking the currents leaving our circuit "negative values" and then adding them, we should arrive at the answer "zero." If both of these current values are equal, then, by using a basic rule of addition that states "when two equal but opposite numbers are added, they cancel and equal zero," you can easily solve the problem. Examples of equal but opposite numbers are +5 and -5.

Using the circuit above as an example, notice that the current leaving the power supply and entering point A, the input to our circuit, is 5 amps. Since this is the current entering the point, we will mark this value +5A.

We mark two currents leaving point A with negative values: $I_1 = -1$ A and $I_2 = -4$ A. By taking the sum of these 2 currents (-1) + (-4) = -5 A, we can state the total value of the two currents leaving the point A as -5 A.

Now, if we add the current entering the point A (+5 A) to the current leaving the point A (-5 A), we get zero for an answer. (+5 A) + (-5 A) = 0. You have just taken the algebraic sum of two values which equals zero. This is an important step to the understanding of Kirchhoff's Current Law.

Let's use point B of the same circuit in Figure 1 as another example. The currents entering point B we will label as $I_1$ (+1 A) and $I_2$ (+4 A). The total current entering point B is $I_1$ (1 A) + $I_2$ (4 A) or + 5A. The ammeter $M_4$ shows 5 amps leaving point B; this can be written as -5 A. The current leaving point B is now -5 A.

Now, we check by adding: (+5 A) + (-5 A) = zero.

That part of Kirchhoff's current law that states "entering any point and leaving any point" can also refer to a resistor branch and could be restated: "entering any parallel resistor branch and leaving any parallel resistor branch." Now the law could look something like this: "the algebraic sum of the currents entering a parallel resistor branch and leaving that same parallel branch must equal zero." Study the illustration below.

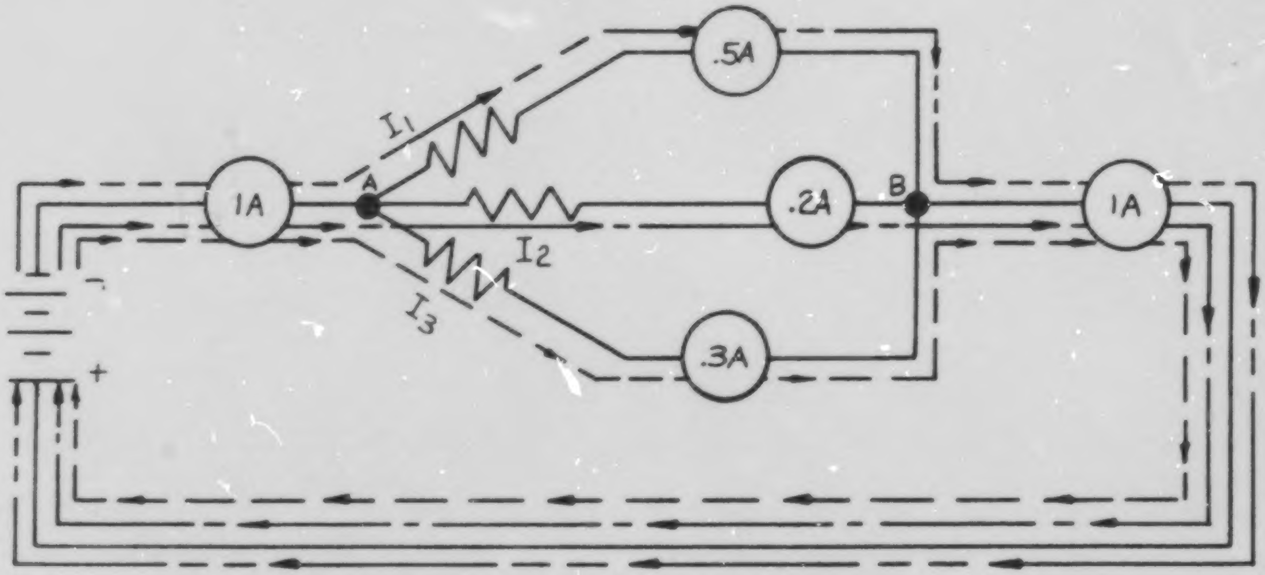
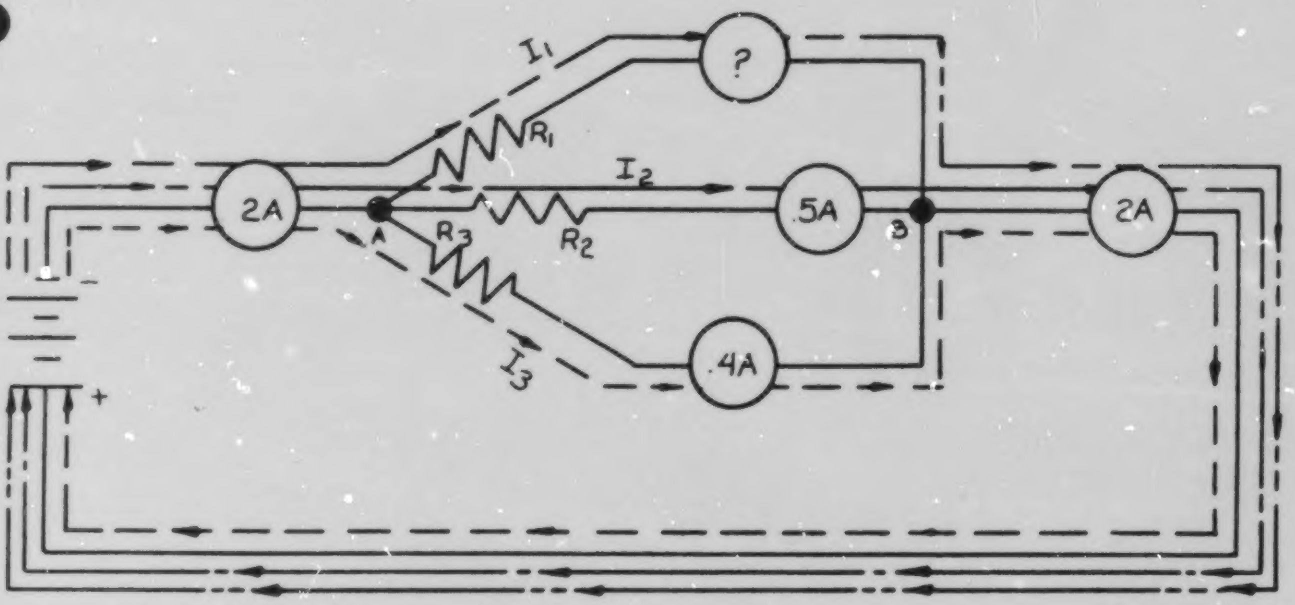


Figure 2

Observe that the current entering this resistor network is equal to 1 amp. The current leaving point A is split into 3 different current paths. But since they are all leaving, you can mark all of them negative values as follows: $I_1 = -.5$ A, $I_2 = -.2$ A, $I_3 = -.3$ A. The total amount of current at point B could be expressed as -1 amp, by adding: $(-.5) + (-.2) + (-.3) = -1$.

Now take the algebraic sum of these two current values, the entering current of +1 amp and the leaving current of -1 amp. $(+1 \text{ A}) + (-1 \text{ A}) = 0$. This is just another application of Kirchhoff's Current Law.

Let's try another application. Study the illustration on the following page.



Kirchhoff's Laws can also be used to solve for an unknown current. The problem is to find the value of current path $I_1$. See if you can follow along with me and come up with the same answer as I do.

1. If $I_t$, or the total current entering the branch of point A is +2A, then -2A must leave the branch at point B.
2. Currents add in parallel circuits. We can account for -.9A of the total -2A by adding current $I_2$ and current $I_3$. (-.5A) + (-.4A) = -.9A. Since these are currents leaving the branch at point B, we can mark the total current at this point as (-.9A + x), the x representing the unknown current $I_1$.
3. Now we can set up an algebraic equation like this:

   $I_t + x + I_2 + I_3 = 0$

   If we substitute our known values for the symbols in the equation, it reads:

   $+2A + x + (-.5A) + (-.4A) = 0$
   $+2A + (-.9A) + x = 0$
   $+1.1A + x = 0$
   $x = -1.1A$

4. For proof, we can substitute the values.

$$I_t + I_1 + I_2 + I_3 = 0$$

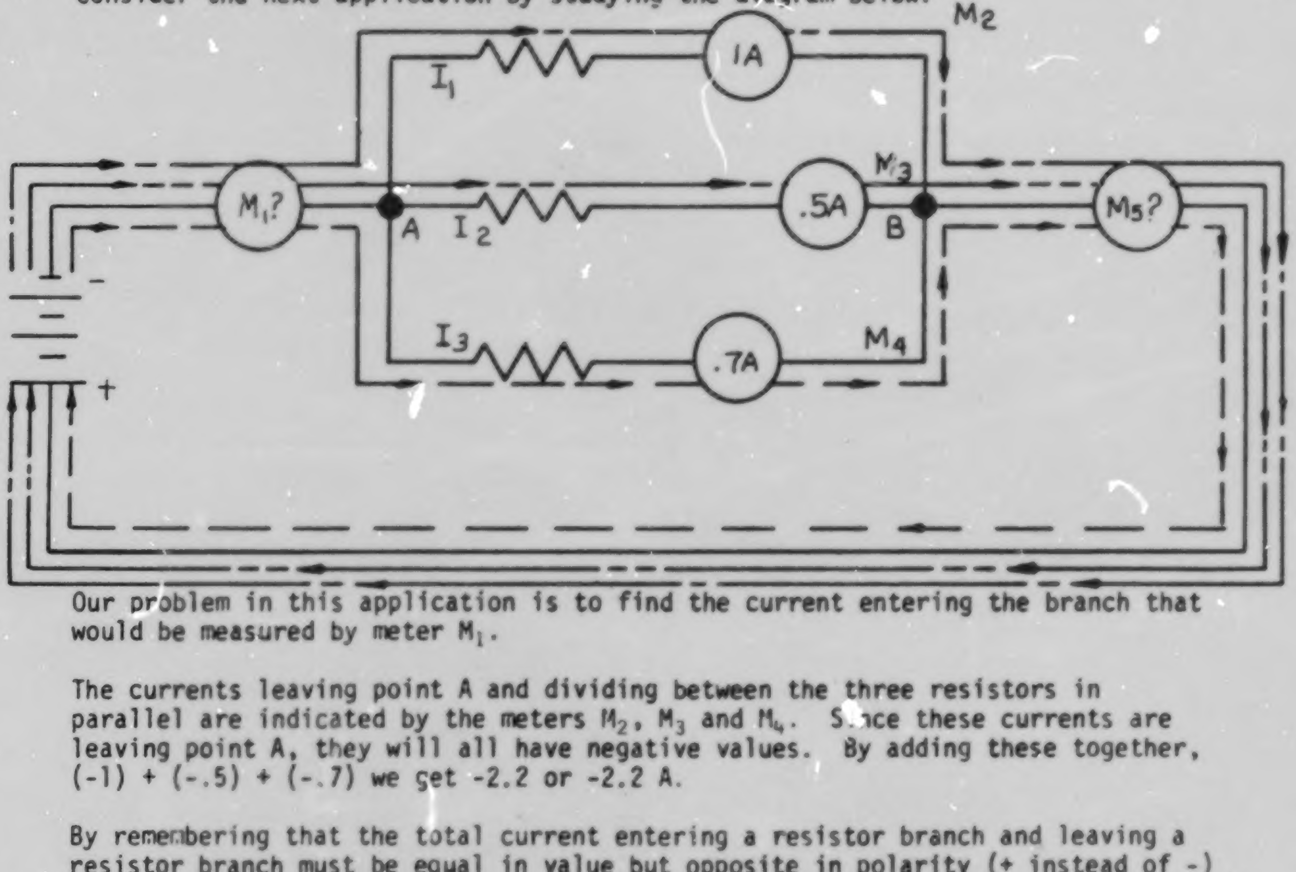
$$+2A + (-1.1A) + (-.5A) + (-.4A) = 0$$

$$+2A + (-2A) = 0$$

$$0 = 0$$

5. By inserting the value (-1.1A) for x, or the unknown $I_1$, we have written an equation which repeats our working statement of Kirchhoff's Law: "The algebraic sum of the currents entering any parallel resistor branch and the currents leaving that same parallel resistor branch must equal zero."

Consider the next application by studying the diagram below.



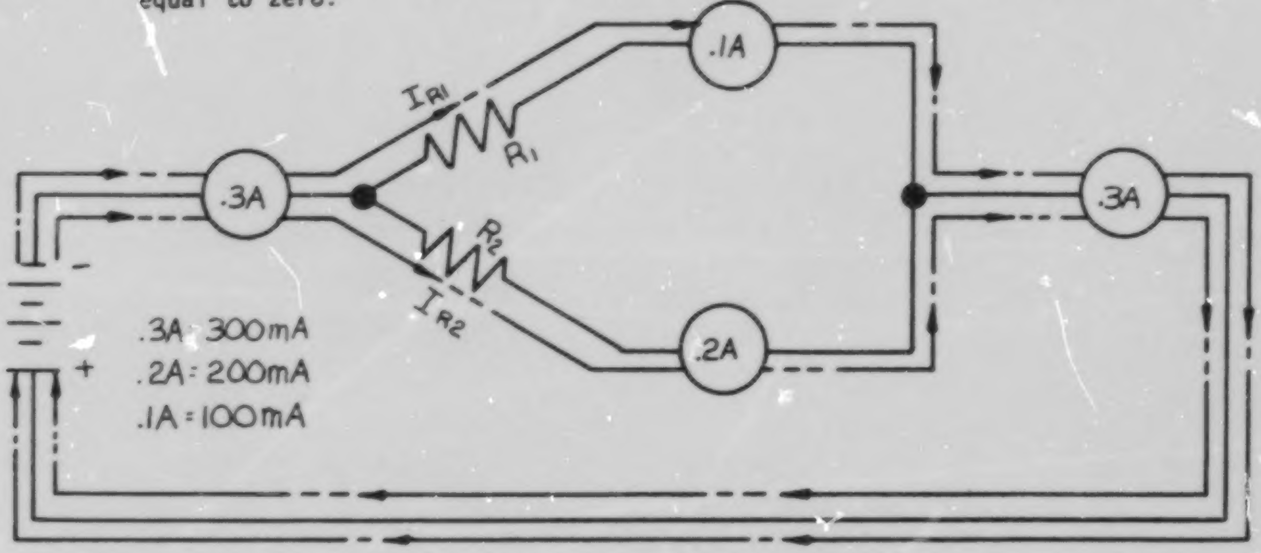
Our problem in this application is to find the current entering the branch that would be measured by meter $M_1$.

The currents leaving point A and dividing between the three resistors in parallel are indicated by the meters $M_2$, $M_3$ and $M_4$. Since these currents are leaving point A, they will all have negative values. By adding these together, (-1) + (-.5) + (-.7) we get -2.2 or -2.2 A.

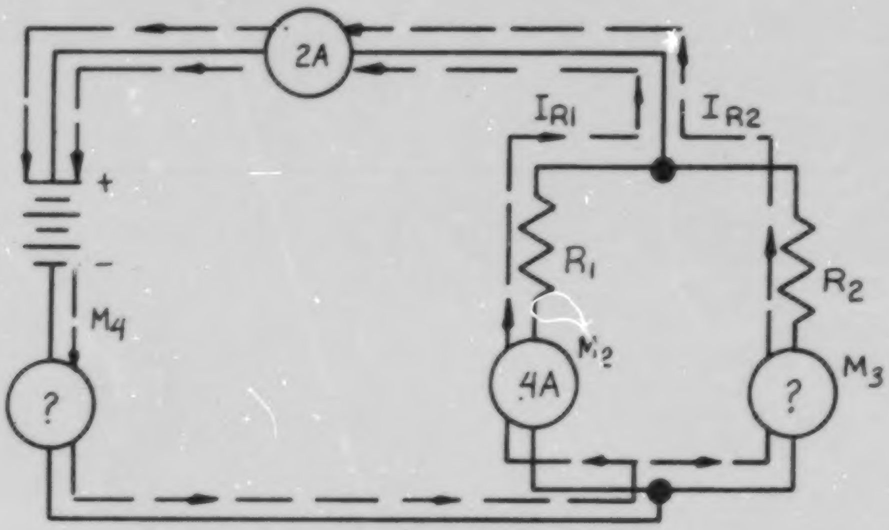
By remembering that the total current entering a resistor branch and leaving a resistor branch must be equal in value but opposite in polarity (+ instead of -) we know that meter $M_1$ will have to read +2.2 A. Let's try the final proof by taking the algebraic sum of those two values. (-2.2 A) + (+2.2 A) = 0. It checks out so 2.2 A is then the current value for meter $M_1$.

## Self-Test

1. Using Kirchhoff's Current Law, perform the addition that will show the algebraic sum of the currents entering any point and leaving any point are equal to zero.


.1A
$I_{R1}$
$R_1$
.3A
$R_2$
$I_{R2}$
.3A
.2A
−
+
.3A = 300mA
.2A = 200mA
.1A = 100mA

2. Using Kirchhoff's Current Law, solve for the current through resistor $R_3$ ($M_3$).


2A
$I_{R1}$
$I_{R2}$
+
−
$R_1$
$R_2$
$M_4$
$M_2$
$M_3$
.4A
?
?

3. Use the diagram in question #2 and the value you arrived at for question #2 to solve for what meter $M_4$ will measure.

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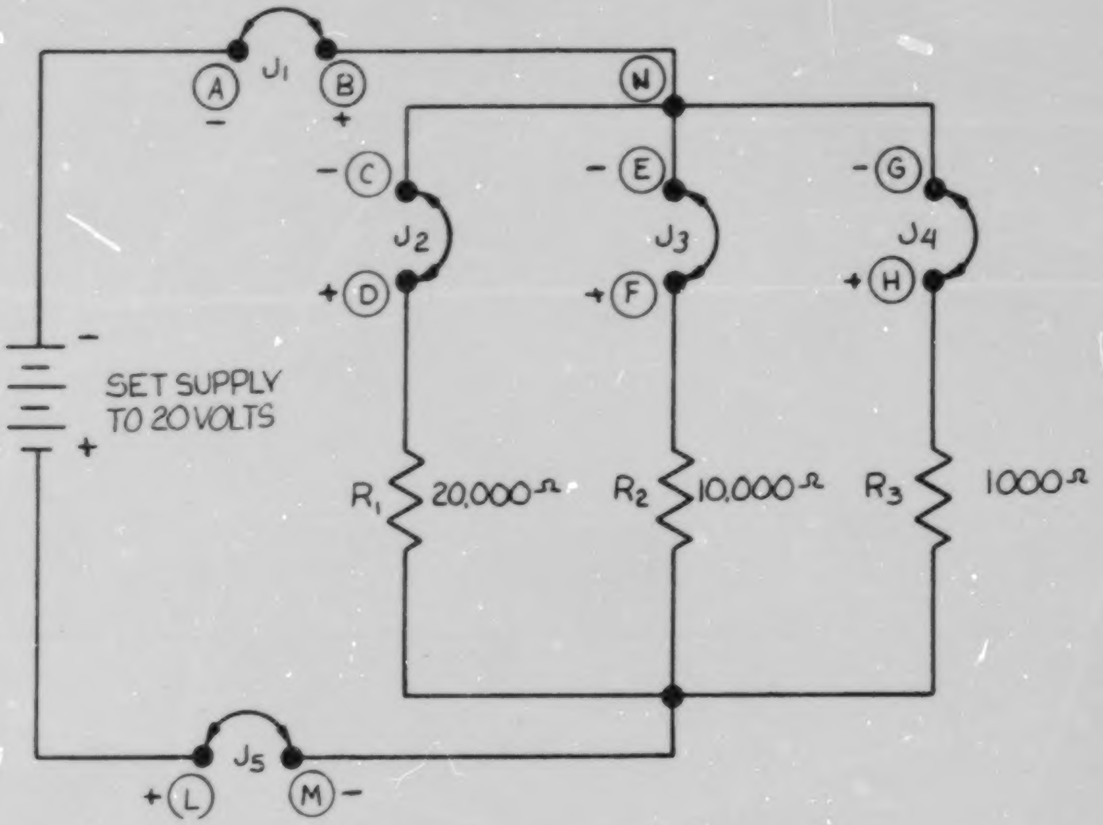
## Task A

Jumper wires will be labelled with the letter J. They will connect two terminals. The terminals are labelled with letters A through M. Remember that the + and - refer to the way you will connect the meters when you remove the jumper wires.

Step 1. Construct the following circuit on your breadboard.



Step 2. Make sure all jumpers are in place.

Step 3. Set your multimeter to read 250 or 300 mA.

Step 4. Remove jumper $J_1$ and install your meter between the two points 'A' and 'B.' Be sure to observe correct polarity when installing your ammeter. Polarity is marked for each jumper.

Step 5. Set your power supply to +20 Volts D.C.

Step 6. Read the current entering the three resistors. __________ mA.

Step 7. Replace jumper $J_1$.

Step 8. Remove jumper $J_5$ and install your meter between points 'L' and 'M.'

Step 9. Read the current leaving the resistor network. __________mA.

DISCUSSION: The current entering the resistor network should equal the current leaving the resistor network. If your readings in Step 6 and Step 9 do not match, consult your instructor for assistance.

Step 10. Replace jumper $J_5$.

Step 11. Remove jumper $J_2$ and insert your meter to measure the current through $R_1$ and record the value. __________mA.

Step 12. Remove jumper $J_2$.

Step 13. Remove jumper $J_3$ and insert your meter to measure the current through $R_2$ and record the value. __________mA.

Step 14. Replace jumper $J_3$.

Step 15. Remove jumper $J_4$ and insert your meter to measure the current through resistor $R_3$ and record the value. __________mA.

Step 16. Record the currents measured for each resistor below from steps 11, 13, and 15.

From Step 11, current through $R_1$ __________ mA
From Step 13, current through $R_2$ __________ mA
From Step 15, current through $R_3$ __________ mA

Step 17. Total all three currents and record the value. __________ mA.

Step 18. Record the current entering the network from Step 6. __________ mA.

Step 19. Record the current leaving the network from Step 9. __________ mA.

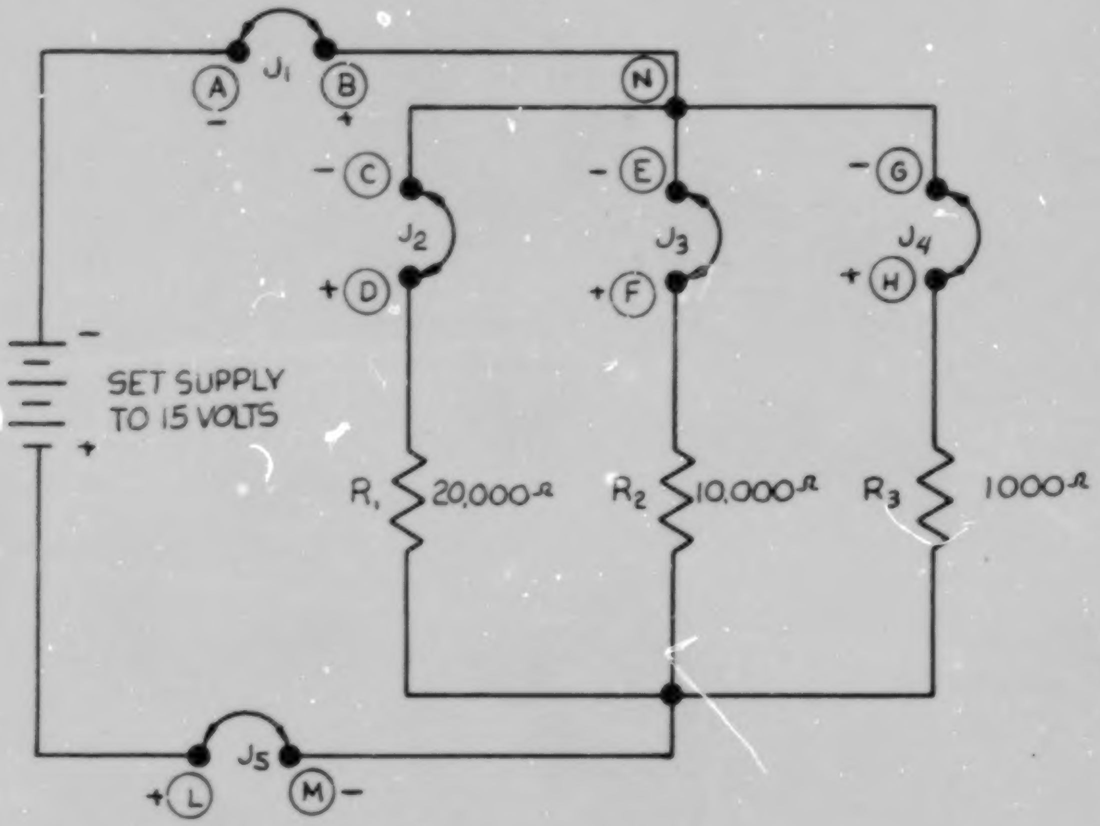
Step 20. Did the three currents for $R_1$, $R_2$, and $R_3$ equal the current entering the network and leaving the network? __________

DISCUSSION: The total amount of current flowing through all three resistors should equal the amount of current entering the three resistors and leaving the three resistors. Due to the resistor tolerances and the exact way you read your meter, your answers may vary plus or minus 10%.

Step 21. Obtain your instructor's evaluation for Task A.

## Task B

Jumper wires will be labelled with the letter J. They will connect two terminals. The terminals are labelled with letters A through M. Remember that the + and - refers to the way you will connect the meters when you remove the jumper wires.



Step 1. Construct the same circuit that you used for Task A as illustrated in the diagram above.

Step 2. Make sure all jumpers are in place.

Step 3. Set your multimeter to read 250-300 mA.

Step 4. Remove jumper $J_1$ and install your meter between the two points 'A' and 'B.' Be sure to observe the correct polarity when installing your ammeter. Polarity is marked for each jumper.

Step 5. Set your power supply to read 15 VDC.

Step 6. Read the current entering the resistor network. ________ mA.

Step 7. Replace jumper $J_1$.

Step 8. Remove jumper $J_5$ and install your meter between points 'L' and 'M.'

Step 9. Record the current leaving the resistor network. __________ mA. The current entering the resistor network should equal the current leaving the resistor network. If your readings in Step 6 and Step 9 do not match, consult your instructor.

Step 10. Replace jumper $J_5$.

Step 11. Remove jumper $J_2$ and insert your meter to measure the current through $R_1$ and record the value. __________ mA.

Step 12. Replace jumper $J_2$.

Step 13. Remove jumper $J_3$ and insert your meter to measure the current through resistor $R_2$ and record the value. __________ mA.

Step 14. Replace jumper $J_3$.

Step 15. Record the total current entering the resistor branch that was measured in Step 6. __________.

Step 16. Record the currents leaving point N that were measured in Steps 11 and 13.

Current through resistor $R_1$ from Step 11 __________ mA.
Current through resistor $R_2$ from Step 13 __________ mA.

Step 17. Total the known currents leaving the branch at point N by adding the two values in Step 16 above. __________ mA.

DISCUSSION: The total current entering the branch or entering point 'N' is measured at jumper $J_1$. Two of the three currents known to be leaving point 'N' were measured at $J_2$ for $R_1$ and at $J_3$ for $R_2$. To visualize these currents, it is best to pencil in those values directly on the circuit diagram used for this task. Since you know that the entering current must equal the leaving current, you can reason that the difference between the known entering currents and the known leaving currents must be the amount of current leaving point 'N' and going through resistor $R_3$.

Step 18. Subtract the two known currents leaving point 'N' from the entering current measured at $J_1$ and record the value. __________ mA.

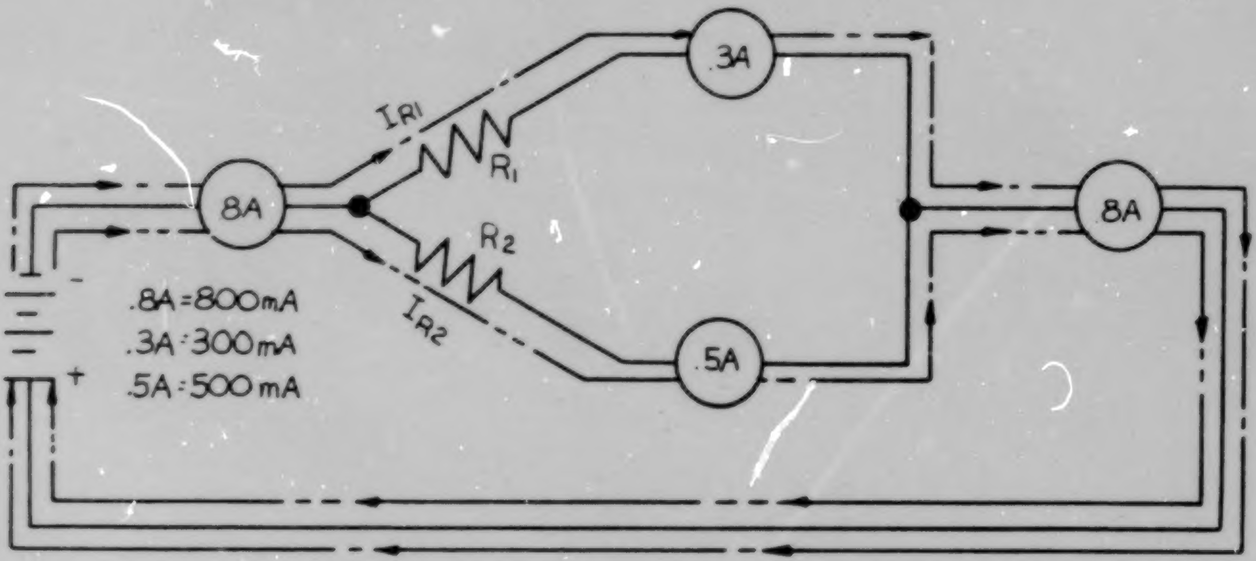
Step 19. Remove jumper $J_4$ and insert your meter to measure the current leaving point 'N' via resistor $R_3$ and record the value. __________ mA.

DISCUSSION: Steps 18 and 19 should be close to the same value. In this task we chose to take a common-sense approach to solving for the unknown current. It is possible to use Kirchhoff's Current Laws to solve this problem. However, you should always try to visualize the solution first. This will be of the greatest benefit when working on an electronic circuit. In the information sheets you will find the method used to solve for this kind of problem using the math in Kirchhoff's laws.

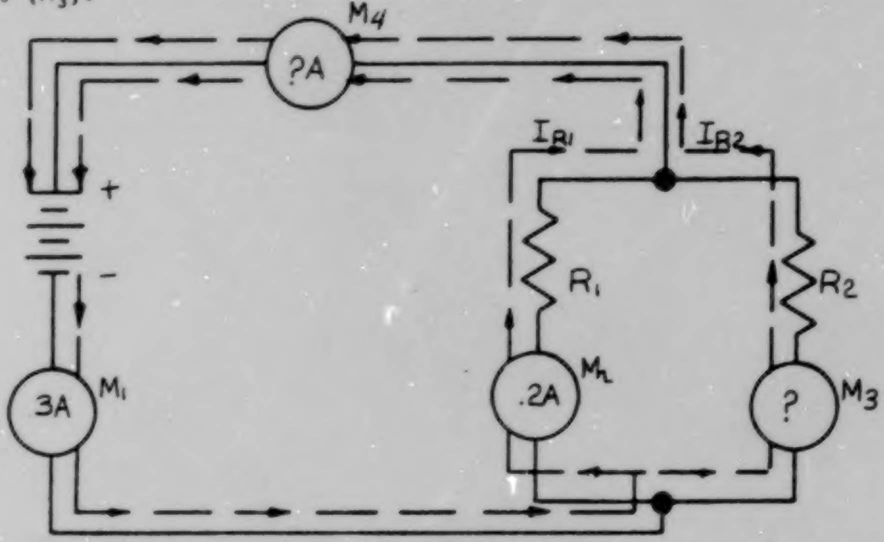
Step 20. Get your instructor's evaluation.

## Final Test

1. Using Kirchhoff's Current Law, perform the addition that will show the algebraic sum of the currents entering any point and leaving any point are equal to zero.


.3A
$I_{R1}$
$R_1$
8A
$R_2$
$I_{R2}$
.5A
.8A
-
+
.8A=800mA
.3A=300mA
.5A=500mA

2. Using Kirchhoff's Current Law, solve for the current through resistor $R_3$ ($M_3$).


$M_4$
?A
$I_{R1}$
$I_{R2}$
+
-
$R_1$
$R_2$
3A
$M_1$
.2A
$M_2$
?
$M_3$

3. Use the diagram in question #2 and the value you arrived at for question #2 to solve for what meter $M_4$ will measure.

# Final Evaluation

| | OK | Re-Do |
|---|---|---|
| Completed Final Test with an accuracy of 80 percent | | |
| Completed Task A on Kirchhoff's Current Laws | | |
| Completed Task B on Kirchhoff's Current Laws | | |

When all checks indicate OK, proceed to the next learning package.

## Answers

1. $I_{R_1} + I_{R_2} + .3A = 0$

   $(-.1A) + (-.2A) + .3A = 0$

2. $M_3$ current equals 1.6A*

   *Algebraic proof optional

   $I_{R_1} + I_{R_2} + 2A = 0$

   $(-4A) + I_{R_2} + 2A = 0$

   $(-.4A) + 2A = -I_{R_2}$

   $1.6A = -I_{R_2}$

   $I_{R_2} = -1.6A$

3. $M_4 = 2A$

   *Current is the same in all parts of a series circuit.

   *Current entering the branch will equal the current leaving the branch.

INSTRUCTIONAL LEARNING SYSTEMS

# 2.11

# KIRCHOFF'S VOLTAGE LAW

## Goal:

The apprentice will be able to use Kirchoff's Law in solving voltage problems.

## Performance Indicators:

1. Describe Kirchoff's Voltage Law.
2. Solve unknown voltages through the application of Kirchoff's Law.

# BASIC ELECTRONICS

# Kirchhoff's Voltage Law
## EL-BE-19

Test Draft
September 1981

## Acknowledgment

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## Objectives

Given:

Resistors of different values

A multimeter

A circuit breadboard for constructing simple circuits

A power supply

A Final Test on Kirchhoff's Voltage Law

The student will:

Mark the correct polarity across resistors in a series circuit.

Apply Kirchhoff's Voltage Law in a simple circuit with one voltage source.

Solve for an unknown voltage using Kirchhoff's Voltage Law.

Complete a Final Test with an accuracy of 80 percent.

## Directions

Obtain the following:

2 each 1000 ohm resistor
1 each 100 ohm resistor
1 each 470 ohm resistor
A multimeter
A power supply capable of 30VDC
A circuit breadboard

## Learning Activities

______ Study the Key Words list.

______ Read the Information Sheets.

______ Do the Self-Test.

______ Do Task A for Kirchhoff's Voltage Law.

______ Do Task B for Kirchhoff's Voltage Law.

______ Complete Final Test.

______ Obtain Final Evaluation.

## Key Words

Kirchhoff's Voltage Law: The algebraic sum of the voltage sources and IR drops must total zero around any closed path.

Algebraic Sum: The result of adding positive and/or negative numbers. In electrical circuits:

A. Voltage drops are assigned a negative value (-).
B. Voltage sources are assigned positive value (+).

Closed Path: Another name for a circuit that makes a complete loop between the plus (+) and minus (-) points of a voltage source.

IR Drop: Same meaning as voltage drop. (Notice the I and R are on the same line. When E = I x R applies to the voltage across a resistor, the letters IR may be used to mean voltage drop.

A. $IR_1$ = voltage drop across resistor $R_1$.
B. $IR_2$ = voltage drop across resistor $R_2$.

Remember that $I_R$ (the R dropped below the I) stands for current flow through a resistor.

R: (symbol) Specifies a certain resistor.

$R_1$ = resistor number 1 in the circuit.

$R_2$ = resistor number 2 in the circuit.

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# Information Sheet

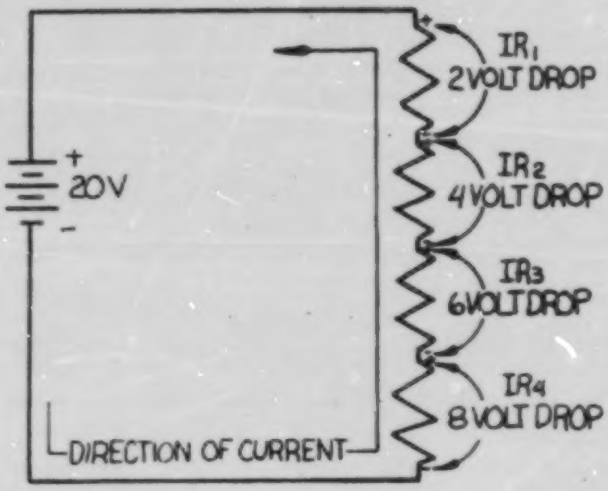
## KIRCHHOFF'S VOLTAGE LAWS FOR ONE SOURCE

Kirchhoff's Voltage Laws are of particular importance because you will use a voltmeter more often than an ammeter in analyzing a circuit. Hence, you will be working with voltages. Technically stated, Kirchhoff's Voltage Law says: "the algebraic sum of the voltage sources and IR voltage drops must total zero around any closed loop." Stated more simply, if you add all the voltage drops together in a series circuit, the total voltage drops will equal the applied voltage. Oh, oh, that word algebraic sum again.

Remember that we can do an algebraic sum because we assign either positive or negative values to our numbers. Voltage drops are assigned negative (-) values and the voltage sources positive (+) values.

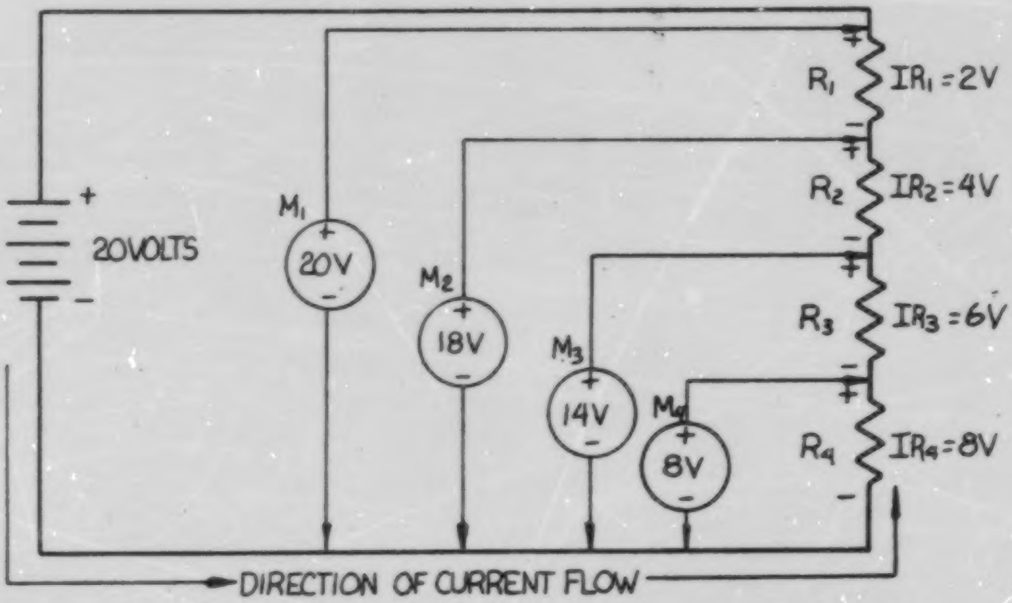
In the following illustration, the voltage drops will be marked as follows: $IR_1 = -2V$, $IR_2 = -4V$, $IR_3 = -6V$ and $IR_4 = -8V$.

When you begin with an applied positive voltage and then have a series of voltage drops, each drop will cause the voltage at the end of a particular resistor to be less positive, or negative, as compared to the applied voltage. This can be more easily seen if you consider the direction of electron current flow through the four series resistors. Electron current always travels from a negative value to a positive value. With this in mind we are able to mark the polarity of the voltage drops acoss each resistor by starting with a (-) value at the bottom of resistor $R_4$ since it is hooked directly to the (-) terminal of our voltage source. We then follow with (-) to (+) markings across each resistor until we get to the positive terminal of the voltage source. To get a better idea of this concept, study the following illustration.



This next illustration is showing what the actual measured voltage would be at the end of each resistor. The meters $M_1$ - $M_4$ would read as follows:

$M_1$ = 20 volts less 0 drop or 20 volts
$M_2$ = 20 volts less the 2 volt drop across $R_1$ or 18 volts
$M_3$ = 18 volts less the 4 volt drop across $R_2$ or 14 volts
$M_4$ = 14 volts less the 6 volt drop across $R_3$ or 8 volts

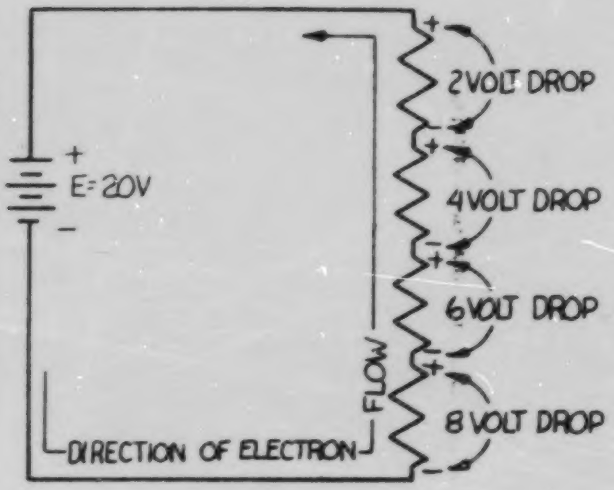


Notice that the meter in each case in the chart above measures what voltage is left over after subtracting the voltage drop. Be careful not to confuse the measured voltages with the voltage drops. The voltage drops are the values that would be read on a meter if the meter was placed directly across (in parallel with) each resistor. The polarity signs (+) and (-) indicate how you would place the meter probes when making these measurements: the (-) side of the meter to the (-) side of the resistor and the (+) side of the meter to the (+) side of the resistor. This type of circuit is often referred to as a voltage divider because the voltage is divided up between the different resistors.

Now, let's get back to the problem of taking the algebraic sum so we can prove Kirchhoff's Voltage Law.

Let's add up all the voltage drops in this series circuit on the following page and see what we get for an answer.

$IR_1$ = 2 volts
$IR_2$ = 4 volts
$IR_3$ = 6 volts
$IR_4$ = 8 volts
20 volts total (Does this number look familiar?)


E=20V
+
-
2 VOLT DROP
4 VOLT DROP
6 VOLT DROP
8 VOLT DROP
DIRECTION OF ELECTRON FLOW

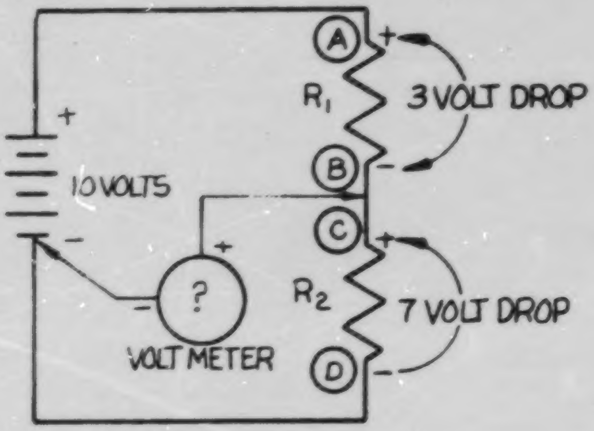
Twenty volts is the same value as the applied voltage from our battery. You may be getting ahead of me, but let's try to apply Kirchhoff's Voltage Law for this circuit.

Remember the law states that the "algebraic sum of the voltage drops plus the applied voltage must equal zero."

Getting back to an earlier rule involving the numbers, remember that the drops will be assigned (-) values and the applied voltage (+) values.

The drops total -20 volts and the source +20 volts. Let's add them together. (-20) + (+20) = 0. This proves that Kirchhoff's Voltage Law works in our circuit.

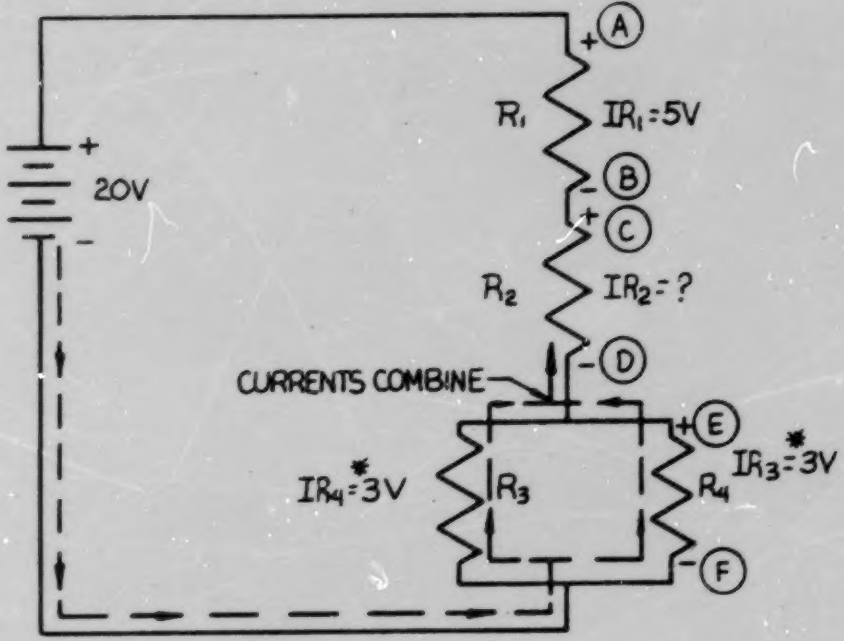
Let's try another example of how we can apply Kirchhoff's Law by considering the following circuit.


A
B
C
D
$R_1$
$R_2$
3 VOLT DROP
7 VOLT DROP
10 VOLTS
?
VOLT METER
+
-

With a three volt drop across $R_1$, what is the voltage you would measure between point B and the negative side of the battery? __________ Did you guess seven volts? You are correct if that is the value you picked. The ten volt supply less the three volt drop across resistor $R_1$ equals seven volts left. NOTICE the measuring from B to the negative terminal of the battery is the same reading that you would get measuring across $R_2$ as the bottom of $R_2$ is connected directly to the negative terminal of the battery.

Let's try a little more difficult circuit and see if you can use the same rule to solve for an unknown voltage.

Study the circuit below:



REMEMBER the drops are considered negative and the source positive. First, let's try a little simpler approach to this problem by putting down some figures that we know about this circuit.

First: Add up the known voltage drops. (-5) + (-3V) = -8V*

*Be careful to include only one 3V drop when adding all the drops together. Voltage drops across parallel resistors are NOT separate drops.

Second: Let's add the voltage drop total to the source.
(-8V) + (+20V) = 12V

Third: We know that the algebraic sum of those two values should equal zero; therefore, the extra 12 volts must be the drop across resistor $R_2$.

Fourth: Let's prove it by adding that value to our voltage drops. We need to add up the drops: (-5V) + (-3V) + (-12V) = -20V. Next add this value to our voltage supply of +20V.

Adding, we get (-20V) + (+20V) = 0. Since the albegraic sum now equals zero, the 12 volts must be the correct drop across $R_2$. Algebraically it could be written as follows:

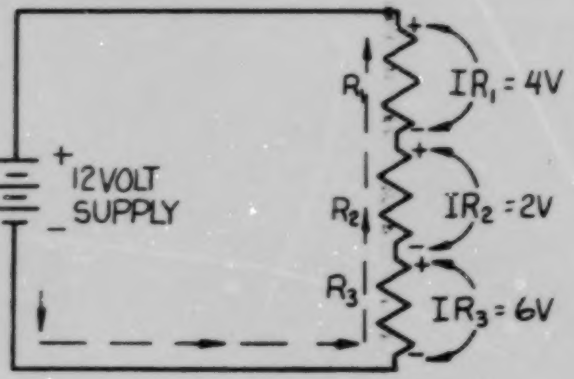
$$
\begin{aligned}
&(-5V) + (IR_2) + (-3V) + (+20V) = 0 \\
&(-8V) + (IR_2) + (20V) = 0 \\
&(-8V) + (20V) = -IR_2 \\
&\qquad (+12V) = -IR_2 \\
&\qquad IR_2 = -12V
\end{aligned}
$$

The above mathematics is an algebraic proof (which may be confusing if your algebra is slipping), but the answer that took all the math is the same answer that you got just using some common sense. Perhaps you can see why we stress understanding the problem first and always trying to visualize a common sense approach before beginning the mathematical approach. In this way, when you do more complicated math, you will have an idea of the correct answer before you begin.

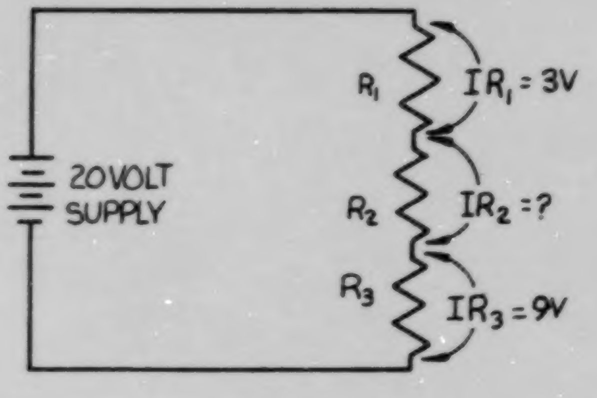
Kirchhoff's Laws can be expanded to include many more complicated circuits, some including two voltage sources. These you will learn in a later course if you decide to continue your electronics training.

## Self-Test

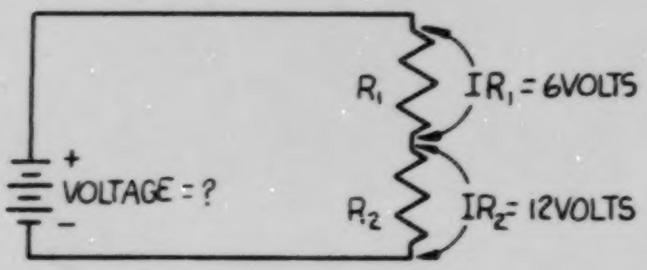
1. Using Kirchhoff's Voltage Law, perform the addition that will show the algebraic sum of the voltage source and IR drops will equal zero around any closed path.


+
12 VOLT
SUPPLY
_
R1
R2
R3
IR1 = 4V
IR2 = 2V
IR3 = 6V

2. Using Kirchhoff's Voltage Law, solve for the voltage drop across $R_2$.


20 VOLT
SUPPLY
R1
R2
R3
IR1 = 3V
IR2 = ?
IR3 = 9V

3. Using Kirchhoff's Voltage Law, solve for the voltage of the battery.


+
VOLTAGE = ?
-
R1
R2
IR1 = 6VOLTS
IR2 = 12VOLTS

## Answers

1. $(-4VIR_1) + (-2VIR_2) + (-6VIR_3) + (12V) = 0$

   $(-12V) + (12V) = 0$

2. $IR_2 = 8V$*

   *Mathematic proof optional

   Possible approach could be simply to use the rule that the sum of all voltage drops must equal the supply voltage.

   $(-3VIR_1) + (IR_2) + (-9VIR_3) + 20 = 0$

   $(-12V) + (20V) = -IR_2$

   $8V = -IR_2$

   $-8V = IR_2$

3. The battery voltage = 18V

   The simplest approach would be to consider that the sum of the voltage drops has to equal the supply.

   Mathematical proof:

   $(-6VIR_1) + (-12VIR_2) + V = 0$

   $-18V + V = 0$

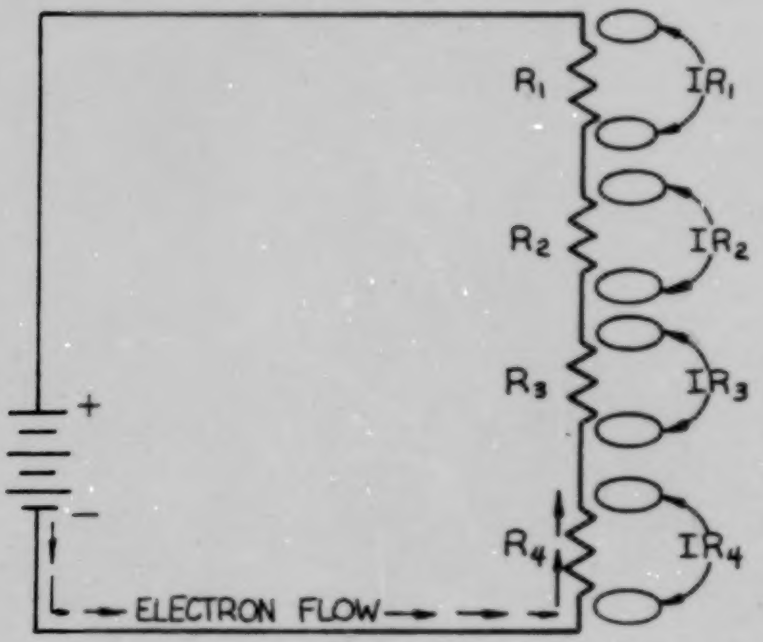
   $V = 18$ volts

## Task A

Obtain the following:

1 each 100 ohm resistor
2 each 1000 ohm resistor
1 each 470 ohm resistor
1 each multimeter
1 each power supply capable of +30VDC
1 each circuit breadboard

Construct the following circuit on your breadboard:



Step 1: Determine the correct polarity (+) and (-) across each resistor and mark the correct symbol at each end of each resistor on the above diagram.

Discussion: Remember to begin at the negative end of $R_4$. That is the end of the resistor connected directly to the (-) side of the voltage supply. Voltage drops are always marked from (-) to (+) across each resistor in the direction of electron current flow.

Step 2: Obtain your instructor's evaluation.

## Task B

Use the same circuit constructed for Task A.

Step 1: Set your power supply to +20VDC.

Step 2: Measure the voltage drops across each resistor and record in the chart below.

Remember to put the meter probes across each resistor according to the polarity you marked on the diagram.

$IR_1$ __________ V

$IR_2$ __________ V

$IR_3$ __________ V

$IR_4$ __________ V

Step 3: Total all the voltage drops in Step 2 and record. __________ V

Step 4: Record the voltage supplied by the power supply. __________ V

Step 5: Do Steps 3 and 4 match? __________.

Discussion: Your answer should be yes. You may notice a slight difference due to rounding off the numbers or slight measurement error. All the voltage drops should add up to equal the applied voltage in any series circuit or closed loop.

Step 6: Complete a mathematical proof using Kirchhoff's Laws that prove the "algebraic sum of the voltage drops plus the applied voltage equal zero." Remember to assign negative values for the drops and positive values for the applied voltage. Put your answer in the space provided below.

Step 7: Obtain your instructor's evaluation.

## Task C

Use the same circuit used in Tasks A and B.

Step 1: Reduce the applied voltage to 15VDC.

Step 2: Measure and record the following voltage drops.

$IR_1$ __________ V

$IR_2$ __________ V

$IR_4$ __________ V

Step 3: Total all the voltage drops from Step 2 and record. __________ V

Step 4: Record the applied voltage from the power supply. __________ V

Step 5: Do the voltage drops total to equal the applied voltage? __________

Step 6: Explain why the two values of voltages are not equal.

Step 7: Without measuring the IR drops with a meter, estimate what the voltage drop should be across resisitor $R_3$. __________ V.

Step 8: Using a meter to measure the voltage drop across $R_3$, measure and record the voltage drop. __________.

Discussion: You should recognize that when ALL the voltage drops are added together they will equal the applied voltage. You should be able to estimate the unknown value of $IR_3$ by taking the difference between what you know to be the total applied voltage and the known voltage drops.

Step 9: Using the value of $IR_3$ obtained from Step 8 above, add up all the voltage drops and record below.

$IR_1$ __________ V

$IR_2$ __________ V

$IR_3$ __________ V

$IR_4$ __________ V

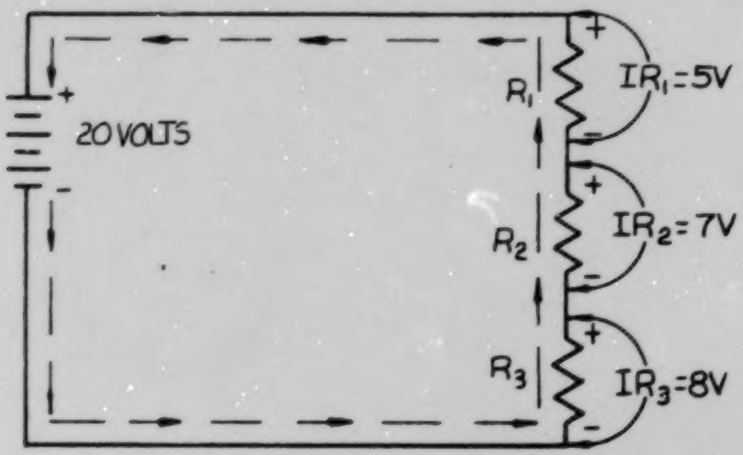
Total of drops __________ Volts

The new value of the total drops should equal the applied voltage in Step 5 because all resistor drops are now included in the answer.

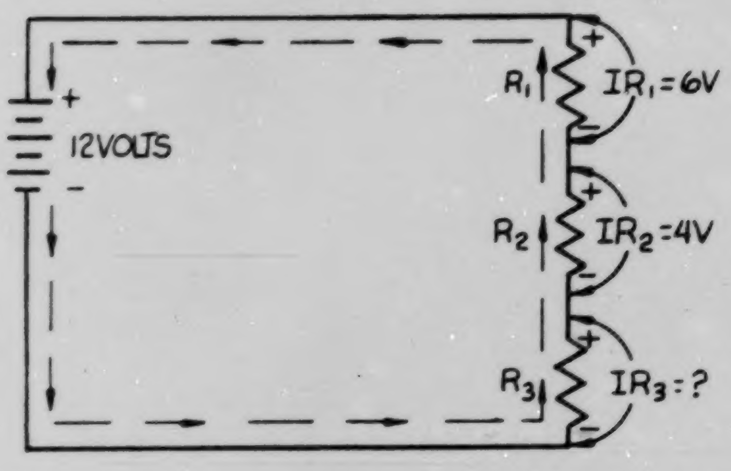
Step 10: Obtain your instructor's evaluation.

## Final Test

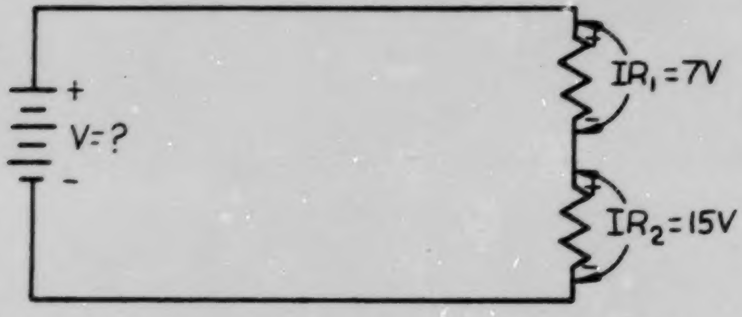
1. Using Kirchhoff's Voltage Law, perform the addition that will show the algebraic sum of the voltage source and IR drops will equal zero around any closed path. Show all work.


20VOLTS
+
-
R1
R2
R3
IR1=5V
IR2=7V
IR3=8V
+
-

2. Using Kirchhoff's Voltage Law, solve for the voltage drop across $R_2$.


12VOLTS
+
-
R1
R2
R3
IR1=6V
IR2=4V
IR3=?

3. Using Kirchhoff's Voltage Law, solve for the voltage of the battery.


V=?
+
-
IR1=7V
IR2=15V

## Final Evaluation

| | OK | Re-Do |
|---|---|---|
| Completed Final Test with an accuracy of 80 percent | | |
| Completed Task A | | |
| Completed Task B | | |
| Completed Task C | | |

When all checks indicate OK, proceed to the next learning package.

INSTRUCTIONAL LEARNING SYSTEMS

# 2.12

## SERIES RESISTIVE CIRCUITS

### Goal:

The apprentice will be able to compute voltage, current and resistance in a series circuit.

### Performance Indicators:

1. Compute current.
2. Compute resistance.
3. Compute voltage.

BASIC ELECTRONICS

# Series Resistive Circuits
## EL-BE-20

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| A power supply and four resistors connected in series | Calculate the total resistance.<br>Calculate the current in the circuit.<br>Calculate the voltage across each resistor.<br>Connect the circuit together and measure the current and the voltages.<br>Connect a circuit consisting of the power supply and a single resistor of equivalent value and remeasure the current. |
| Questions and problems | Complete a Final Test with an accuracy of 85 percent. |

## Directions

Obtain the following material:

DC power supply

Resistors (1/4 W, 2%)* 330, 470, 1k, 1.5k, and 3.3k ohms

Any DC voltmeter and ammeter (separate meters or a combination meter)

Interconnecting leads or wires to connect the parts

## Learning Activities

______ Read Key Words list

______ Read Information Sheets

______ Do Self-Tests

______ Do Task

______ Do Final Test

______ Obtain Final Evaluation

---

*1/4 watt minimum, 2 percent suggested tolerance

# Key Words

Absorbed energy/power: Power or energy consumed by an electrical component or circuit.

Charge (to): To supply power to a device that can store energy such as a battery.

Equivalent circuit: An electrical circuit that is equivalent to another more complicated circuit in the sense that it draws the same amount of current from a voltage source as does the original circuit.

Equivalent resistance: A single resistance equivalent in value to the combination of two or more other resistors.

IR drop: The voltage drop associated with a resistor.

Power dissipation: Power absorbed in an electrical component.

Series connection: A method of connecting electrical components so that one end and only one end of each component connects to each of the other components.

Supplied or delivered power/energy: Power or energy produced or given up by a source such as a voltage source like a power supply or battery.

Voltage drop: A decrease in voltage caused by an electrical component absorbing energy or power; current entering the more negative end of the component results in a voltage drop across the component in the circuit.

Voltage rise: An increase in voltage caused by a source supplying energy or power to a circuit.

# Information Sheet No. 1

When two or more resistors are connected end to end, they are in series. One lead of one resistor connects to only one lead of the next resistor and so on. The current leaving one resistor is exactly the same current that enters the next resistor. So the current is always the same for any resistors in series with each other. In Figure 1 the current is 12.5 mA in each of the three resistors and also in the voltage source.

Suppose you were not told what the current was. You only know the resistance values and the source voltage. You can solve for the current by knowing how resistors combine when they are in series.

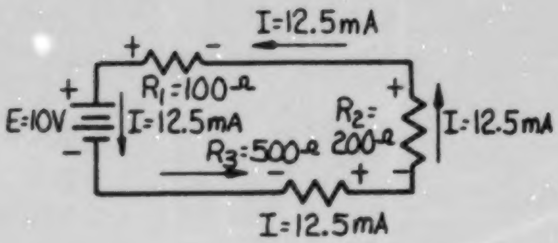


Figure 1

## Resistance in Series Adds

Suppose a piece of wire is cut from a spool of wire, and then a second piece is cut that is twice as long. The second piece will have twice as much resistance as the first. Also, two pieces of the same length connected together in series will have twice the resistance of each of the single pieces.

In Figure 1, the total resistance in the circuit (called $R_t$) is the sum of the resistances of all the resistors.

$$\begin{aligned} & R_t = R_1 + R_2 + R_3 \\ R_1 = 100\ \Omega,\ R_2 = 200\ \Omega,\ R_3 = 500\ \Omega, \text{ so } & R_t = 100 + 200 + 500\ \Omega \\ & R_t = 800\ \Omega \end{aligned}$$

The total resistance of resistors in series is always LARGER than the resistance of any one of the resistors.

To find the current in the circuit replace all of the resistors by a single resistor with a value equal to the total resistance. This resistance is called the equivalent value of resistance or just equivalent resistance.

Figure 2 is equivalent to Figure 1 in the sense that the same current flows from the voltage source.

Apply Ohm's law to the circuit of Figure 2.

$$I = \frac{E}{R_t}$$

$$I = \frac{10V}{800\Omega}$$

$$I = 0.0125\ A = 12.5\ mA$$

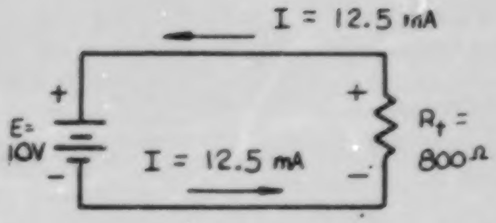
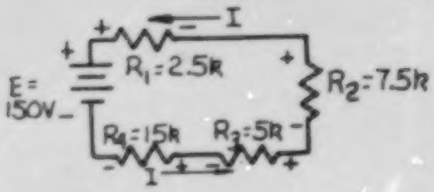
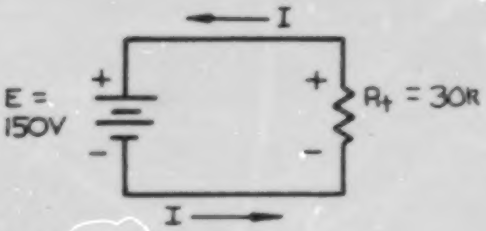

I = 12.5 mA
+
E=
10V
–
I = 12.5 mA
+
–
$R_t$ =
800Ω

Figure 2

Example 1


I
+
–
+
E=
150V
–
$R_1$=2.5k
+
$R_2$=7.5k
–
$R_4$=15k
$R_3$=5k
–
+
–
+
I


I
E =
150V
+
–
+
$R_t$ = 30k
–
I

Equivalent Circuit

$$R_t = R_1 + R_2 + R_3 + R_4$$
$$R_t = 2.5k + 7.5k + 5k + 15k$$
$$R_t = 30k$$

$$I = \frac{E}{R_t} \qquad E = 150V;\ R_t = 30k$$

$$I = \frac{150V}{30k}$$

You should remember from the Metric Prefix package k = 1000 and $m = \frac{1}{1000} = 0.001$.

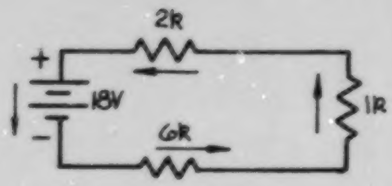
So $I = \frac{150V}{30 \times 1000\ \Omega} = 0.005\ A = 0.001 \times 5 = 5\ mA$

Also, $I = \frac{150V}{30k} = \frac{150}{30} = mA = 5\ mA$ since $k = \frac{1}{m}$ and $m = \frac{1}{k}$

## Self-Test No. 1

1. Four resistors are connected in series. Their resistances are 125, 250, 75, and 300 ohms respectively. What is the equivalent value of resistance for the series combination?

2. Determine the value of current in each resistor and the source.



# Information Sheet No. 2

Review of KVL

Now that you have learned how to calculate the current in a series circuit, you can prove Kirchhoff's voltage law still works.

Going back to Figure 1 before the example, you can calculate each of the voltage drops. The current was 12.5 mA in the circuit of Figure 1.

$$I \times R = E$$

For $R_1$ which was 100 Ω, the drop is $IR_1 = (12.5\text{mA}) \times (100\ \Omega) = 1.25$ volts
For $R_2$ 200 Ω, $IR_2 = (12.5\text{mA}) \times (200\ \Omega) = 2.50$ volts
For $R_3$ 500 Ω, $IR_3 = (12.5\text{mA}) \times (500\ \Omega) = \underline{6.25 \text{ volts}}$
The total voltage drop is 10.00 volts

The source voltage is E = 10 volts, so the source voltage minus the voltage drops is 10V - 10V = 0 volts.

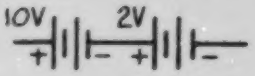
Also, in Example 1, I = 5 mA and,

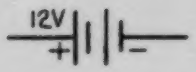
$IR_1 = (5\text{mA}) \times (2.5\text{k}) = 12.5\text{V}$ $R_1 = 2.5\text{k}$
$IR_2 = (5\text{mA}) \times (7.5\text{k}) = 37.5\text{V}$ $R_2 = 7.5\text{k}$
$IR_3 = (5\text{mA}) \times (5\text{k}) = 25\text{V}$ $R_3 = 5\text{k}$
$IR_4 = (5\text{mA}) \times (15\text{k}) = \underline{75\text{V}}$ $R_4 = 15\text{k}$
Total drop $= 150\text{V}$ $E = 150\text{V}$

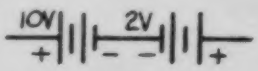
so, E - 150 = 150 - 150 = 0, and KVL is again demonstrated.

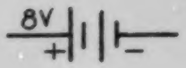
Voltage Sources in Series

Voltage sources in series add in the same way as resistors, with one additional concern. The polarity of each source must be the same before the values are added. If the polarity is opposite, then the value must be subtracted instead of added.

For example 

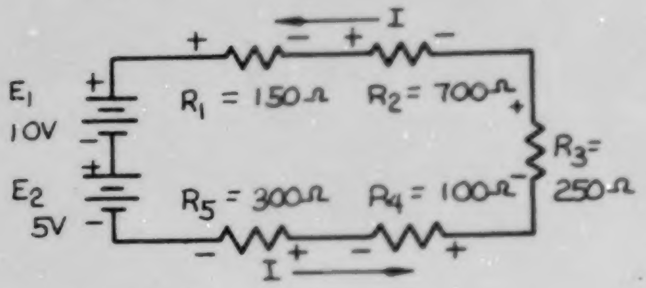
is equivalent to 

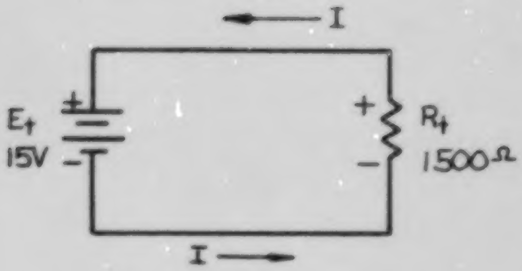
and 

is equivalent to 

Here are two examples to show how to solve series circuits with more than one voltage source.

Example 2:





Equivalent Circuit

In the equivalent circuit

$$E_t = E_1 + E_2 \quad \text{and } R_t = R_1 + R_2 + R_3 + R_4 + R_5$$

$$15V = 10V + 5V \quad 1500\,\Omega = 150 + 700 + 250 + 100 + 300\Omega$$

So $I = \frac{E}{R}$ = where $E_t = 15V$ and $R_t = 1500\Omega$

$$I = \frac{15V}{1500\Omega} = 0.01\text{ A} = 10\text{ mA}$$

KVL also holds for series circuits with more than one source, but it must be modified slightly.

The sum of voltage RISES from voltage sources MINUS the sum of voltage DROPS equals ZERO or the sum of voltage RISES EQUALS the sum of voltage DROPS.

The voltage rises are always due to a source. If the current enters the (+) positive end, it is a voltage rise.

The voltage drops are almost always due to resistors (IR drops), but may also be due to a source that is charging, which means absorbing energy rather than supplying energy. If the current enters the (-) negative end, then it is a voltage drop whether it is a resistor or a source.

In this example (Example 2) there are two voltage rises, $E_1$ and $E_2$. Notice that the current is entering the (+) end of each source.

$E_1 = 10V$ and $E_2 = 5V$, so the total voltage rise is $10V + 5V = 15V$.

There are five voltage drops. Remember that IR means voltage drop. Notice the current enters the (-) end of each one.

$IR_1 = (0.01A) \times (150\Omega) = 1.5V$ $\quad I = 0.01$ A $\quad R_1 = 150\Omega$

$IR_2 = (0.01A) \times (700\Omega) = 7.0V$ $\quad R_2 = 700\Omega$

$IR_3 = (0.01A) \times (250\Omega) = 2.5V$ $\quad R_3 = 250\Omega$

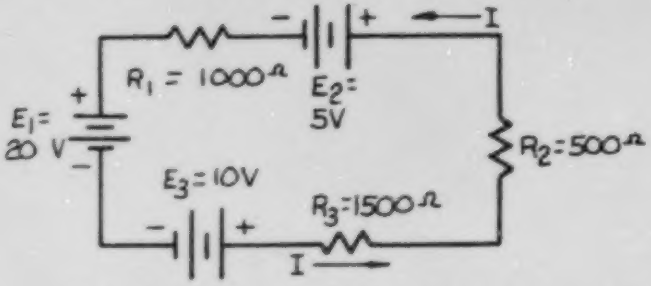
$IR_4 = (0.01A) \times (100\Omega) = 1.0V$ $\quad R_4 = 100\Omega$

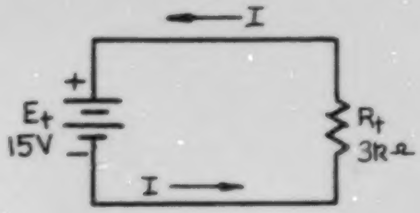
$IR_5 = (0.01A) \times (300\Omega) = \underline{3.0V}$ $\quad R_5 = 300\Omega$

Total drops $= 15.0V$

and you see that total rise (15V) equals total drop (15V).

Example 3:





Equivalent Circuit

$R_t = R_1 + R_2 + R_3$ $\qquad E_t = E_1 + E_2 - E_3$

$R_t = 1000 + 500 + 1500 = 3000\,\Omega$ $\qquad E_t = 20 + 5 - 10 = 25 - 10 = 15V$

$$I = \frac{E}{R_t} = \frac{15V}{3000} = .005A$$

also since $3000\,\Omega = 3k$

$$I = \frac{15V}{3k} = \frac{15}{3}\ mA = 5mA$$

The sum of the voltage rises is only $E_1 + E_2$ since current is entering the (-) end of $E_3$.

So voltage rise equals 20V + 5V = 25 volts

The voltage drops are:

$IR_1 = (5mA) \times (1000\Omega) = 5V$

$IR_2 = (5mA) \times (500\Omega) = 2.5V$

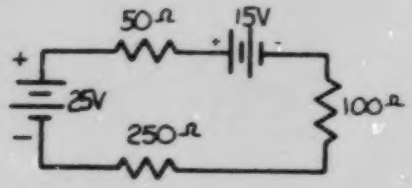
$IR_3 = (5mA) \times (1500\Omega) = 7.5V$ and because the current is entering (-) end of $E_3$

$E_3 = \underline{10V}$

total drops $= 25V$ which equals the total rise of 25 volts.

## Self-Test No. 2

1. Calculate $E_t$.
2. Calculate $R_t$.
3. Determine the value and direction of the current in each element.


50Ω
15V
+
-
+
-
25V
250Ω
100Ω

# Information Sheet No. 3

## Power in Series Circuits

The total power absorbed in any circuit is the sum of the powers absorbed in each element of the circuit. It doesn't matter how the elements are connected so they can be connected in other arrangements besides in series.

The law of conservation of energy says that the total energy supplied must equal the total energy absorbed.

This means that the total power supplied by all of the sources that are supplying power must equal the total power absorbed by resistors (or sources) in the circuit. If a source is charging, it is absorbing power. It is charging if the current enters the (-) end as it does in a resistor.

Review the formulas from the POWER/WATT'S LAW package. The necessary formulas are repeated in the REVIEW OF FORMULAS section below.

Refer back to Example 3 to demonstrate the use of these formulas in series circuits.

$$E \times I = P$$

$E_1$ is supplying $E_1 \times I = (20V) \times (5mA) = 100\ mW$

$E_2$ is supplying $E_2 \times I = (5V) \times (5mA) = \underline{25\ mW}$

Total power supplied $= 125\ mW$

$E_3$ is absorbing $E_3 \times I = (10V) \times (5mA) = 50\ mW$

$R_1$ is absorbing $I^2 \times R_1 = (5mA)^2 \times (1k) = 25\ mW$

or $(.005)^2 \times (1000) = .025W\ (25mW)$

$R_2$ is absorbing $I^2 \times R_2 = (5mA)^2 \times (.5k) = 12.5mW$

$R_3$ is absorbing $I^2 \times R_3 = (5mA)^2 \times (1.5k) = 37.5mW$

Total power absorbed $= 125\ mW$ which equals total power supplied

CIRCUIT VALUES

$E_1 = 20V$
$E_2 = 5V$
$E_3 = 10V$
$I = 5mA = .005A$
$R_1 = 1000 = 1k$
$R_2 = 500 = 0.5k$
$R_3 = 1500 = 1.5k$

REVIEW OF FORMULAS FOR SERIES CIRCUITS

$R_t = R_1 + R_2 + R_3 +$ and so on

$E_t = E_1 \pm E_2 \pm E_3 \pm$ and so on; ± means + or - depending on polarity

$P = E \times I$ for sources or resistors

$P = I^2 \times R$ ←
$P = \frac{E^2}{R}$ ← for resistors only

## Self-Test No. 3

1. Calculate the power supplied or absorbed in each of the elements in Self-Test 2.

2. Show that the power absorbed equals the power supplied in question 1.

# Self-Test No. 4

1. When two or more resistors are in series they have the same

   a. voltage. b. current. c. power. d. value.

2. To find the equivalent value of resistors in series, the resistances must be

   a. added. b. subtracted. c. multiplied. d. divided.

3. To find the equivalent value of batteries in series, the voltages must be

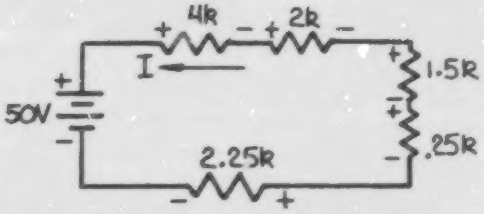
   a. added. b. subtracted.
   c. either added or subtracted depending on polarity.
   d. either multiplied or divided.

4. Four resistors (100, 200, 500, and 50 ohms) are in series. The equivalent resistance is

   a. 150 ohms. b. 500 million ohms. c. 850 ohms. d. 1300 ohms.

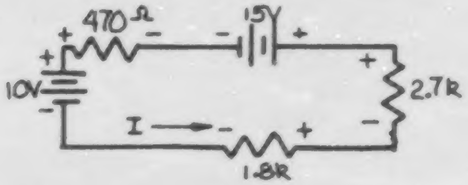
5. Solve for the value of current:

   a. 3.3 mA
   b. 5 A
   c. 5 mA
   d. .05 A



6. Solve for the value of current:

   a. 5.03 mA
   b. 25 mA
   c. 1.05 mA
   d. 1.05 A



7. Solve for the power supplied by the 50 V battery in question #5.

   a. 250 mW b. 50 mW c. 25 W d. 150 mW

8. Solve for the power absorbed by the circuit in question #6.

   a. 5 mW b. 15 mW c. 75 mW d. 126 mW

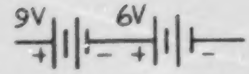
9. Find the total equivalent voltage of the sources:

a. 3V b. 6V c. 9V d. 15V

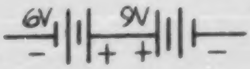
A. ____

B. ____

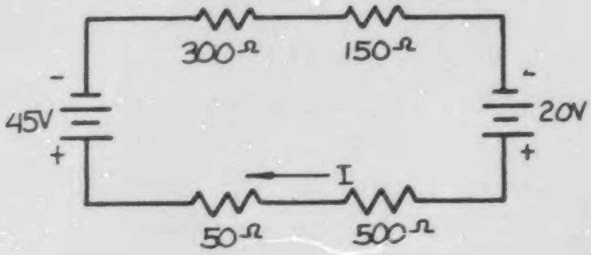
A.



B.



10. Find the equivalent value of resistance and voltage in the circuit; then solve for the value and direction of current.


300Ω
150Ω
-
45V
+
-
20V
+
I
50Ω
500Ω

# Task

Given a power supply and the following resistors all connected in series, 330, 470, 1 k, and 1.5 k ohms each. Set the supply to about 9 volts. Measure the supply voltage with the voltmeter.

Calculate the total or equivalent value of resistance.

Calculate the value of current that would flow in the circuit if they were all connected in a closed (unbroken) circuit in series. See the figure.

Calculate the voltage that would exist across each resistor in the circuit.

Connect the complete circuit according to the figure using the interconnecting leads and including the ammeter. Measure the current with the ammeter.

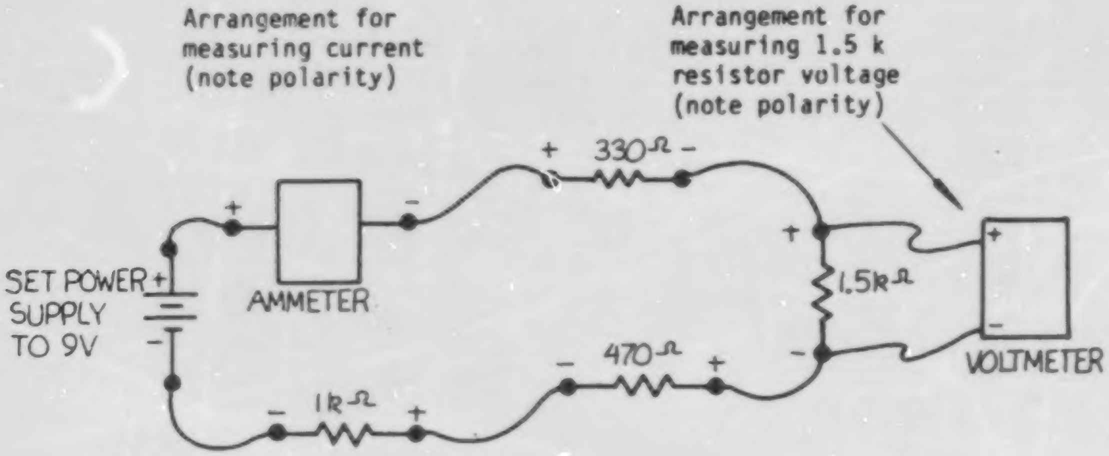
Disconnect the ammeter and measure the voltage across each resistor with the voltmeter. Remember to replace the ammeter with a short circuit to complete the circuit.

Obtain a single resistor of value equal to the value calculated for the total resistance. Connect this resistor alone with the ammeter to the power supply and measure the current. Remember the resistor, ammeter, and battery must be connected in a closed SERIES circuit.

All of the currents calculated or measured should be the same. The reasons they may differ are:

1. The meter causes errors in measurement.
2. The actual values and printed values of the parts may differ.
3. You may have made an error in calculation or measurement.

Have your instructor check your results.

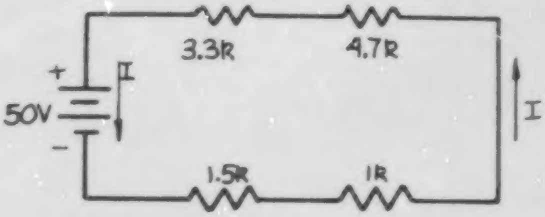

Arrangement for measuring current (note polarity)
Arrangement for measuring 1.5 k resistor voltage (note polarity)
+
330Ω
-
+
-
AMMETER
SET POWER SUPPLY TO 9V
+
-
+
1.5kΩ
-
+
-
VOLTMETER
-
470Ω
+
-
1kΩ
+

# Final Test

1. When resistors or other electrical components are connected in series, the current in each of the components will always be

   a. zero.  b. the same.  c. different.

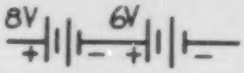
2. Five resistors are connected in series. Two of the resistors are 50 ohms each, and three of the resistors are 20 ohms each. What is the equivalent resistance?



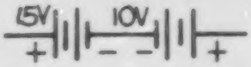
3. Solve for the equivalent resistance in the circuit.

4. Solve for the current in the circuit.

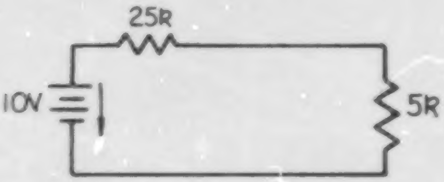
5. What is the total equivalent voltage of the two sources connected as shown?



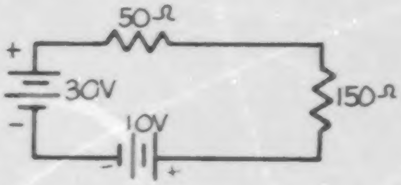
6. What is the total equivalent voltage of the two sources connected as shown?



7. A 5k resistor and a 25k resistor are connected in series to a voltage source. Which resistor is absorbing the greater amount of power? Calculate the power in the 5k resistor if the voltage source is 10 volts. Calculate also the power delivered by the 10 volt source. Remember to solve for the current first!



8. Solve for the value and direction of the current.



# Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Calculated resistance and current. | | |
| Calculated voltages. | | |
| Current measured in original circuit. | | |
| Voltages measured in original circuit. | | |
| Current measured in equivalent circuit. | | |
| Final Test 85%. | | |

When all checks indicate OK, proceed to the next learning package.

# Answers

## Answers to Self-Test #1

1. $R_t$ = 750 ohms; $R_t$ = 125 + 250 + 75 + 300 ohms

2. The current is the same for all series elements.

   I = 2 mA or 0.002 A; $I = \frac{E}{R_t}$ ; $R_t$ = 2k + 1k + 6k or $R_t$ = 9k

   $I = \frac{18V}{9k}$ or I = 2 mA

   also $I = \frac{18V}{9000}$ or I = 0.002 A or 2 mA

## Answers to Self-Test #2

1. $E_t$ = 10V (same polarity as 25V source); $E_t$ = 25 - 15 volts

2. $R_t$ = 400 Ω; $R_t$ = 50 + 100 + 250Ω

3. I = 0.025 A or 25 mA in each element;

   $I = \frac{E_t}{R_t}$ ; $I = \frac{10V}{400\Omega}$

| Direction: | | |
|---|---|---|
| | 25V | down |
| | 50Ω | to left |
| | 15V | to left |
| | 100Ω | up |
| | 250Ω | to right |

## Answers to Self-Test #3

1. $P_{25V}$ = 0.625W supplied since current is leaving (-) end

   $P_{15V}$ = 0.375W

   $P_{50V}$ = 0.3125W

   $P_{100V}$ = 0.0625W absorbed since current is entering (-) end

   $P_{250V}$ = 0.15625W

   Equations used: For sources (either supplying or absorbing) P = ExI
   For resistors $P = I^2R$

   I = 0.025 A in all cases; E or R depending on value for source or resistor considered.

2. Total power supplied = 0.625W
   Total power absorbed = 0.625W = 0.3125 + 0.0625 + 0.15625 + 0.375W

   $P_{absorbed} = P_{supplied}$ since
   0.625W = 0.625W

Answers to Self-Test #4

1. b. current

2. a. added

3. c. either added or subtracted depending on polarity

4. c. 850 ohms

5. c. 5 mA

6. a. 5.03 mA

7. a. 250 mW = ExI = 50x5mA;
also = $I^2 4k + I^2 2k + I^2 1.5k + I^2 .25k + I^2 2.25k = I^2 10k$
since power supplied equals power absorbed

8. d. 126 mW = $I^2(4970)$ = (25V)xI

9. A. d. 15V = 6V + 9V
B. a. 3 V = 9V - 6V

10. $R_t = 300 + 150 + 500 + 50 = 1000\,\Omega$

$$I = \frac{25V}{1000\Omega} = 0.025\text{ A} = 25\text{ mA}$$

INSTRUCTIONAL LEARNING SYSTEMS

# 2.13

# PARALLEL RESISTIVE CIRCUITS

## Goal:

The apprentice will be able to calculate current and resistance in a parallel resistive circuit.

## Performance Indicators:

1. Calculate total resistance.
2. Calculate total current.

# BASIC ELECTRONICS

# Parallel Resistive Circuits

## EL-BE-21

Test Draft
September 1981

## Acknowledgment

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## Objectives

Given:

A power supply and 4 resistors connected in parallel

An ammeter and voltmeter

A resistor equal in value to the 4 parallel resistors

Questions and problems

The student will:

Calculate the total resistance.

Calculate the current in each resistor.

Calculate the total supply current.

Connect the circuit together and measure the currents.

Connect the supply to a single resistor of equivalent value and remeasure the supply current.

Complete a Final Test with an accuracy of 85 percent.

## Directions

Obtain the following materials:

A DC power supply

Resistors (1/4 W, 2%)* 1k, 2.7k, 3.3k, 4.7k, 8.2k ohms

Any DC voltmeter and ammeter (separate meters or a combination meter)

Interconnecting leads or wires to connect the parts

*1/4 watt minimum, 2% suggested tolerance

## Learning Activities

______ Study the Key Words list.

______ Read the Information Sheets.

______ Do the Self-Test.

______ Do the Tasks.

______ Do the Final Test.

______ Obtain Final Evaluation.

## Key Words

Conductance (G): The property of a component that allows current to flow: the larger the conductance, the larger the current; the opposite of resistance.

Mho (℧): A unit for conductance: 1 mho equals 1 amp divided by 1 volt.

Parallel connection: A method of connecting electrical components between or across the same two voltage points in a circuit.

Parallel circuit: A circuit where all the components are connected in parallel.

Sieman (S): A more modern unit for conductance, equal to a mho.

Short circuit: A condition where the circuit resistance is zero.

# Information Sheet

A parallel circuit is one in which all of the components are connected in parallel. That means that each component is connected between or across the same two points. Figure 1 shows a parallel circuit and the two points are labeled point A and point B. As you can see, the voltage supply is also connected between the two points and determines the voltage between points A and B. The voltage across each and every component has to be the source voltage, and for this reason there is only one voltage, the source voltage, in a parallel circuit. The current which the source produces divides at point A into the separate current paths through each resistor. These separate currents recombine at point B to provide the same current entering the source as that leaving the source. As you learned in the Kirchhoff's Current Law package,

$I_t = I_1 + I_2 + I_3$ or in this case:

$I_1 = 0.5A$, $I_2 = 1A$, and $I_3 = 2A$ so,

$3.5A = 0.5A + 1A + 2A$ or

$3.5A = 3.5A$

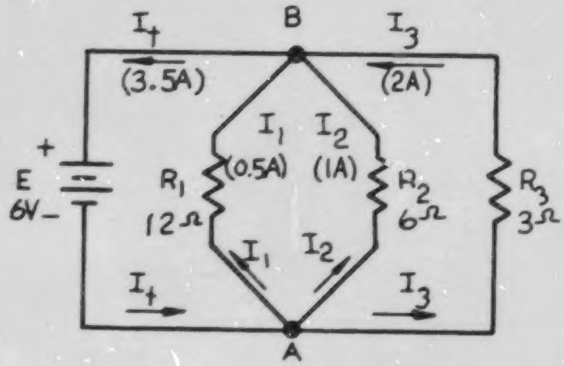


Figure 1

Many times a parallel circuit will be drawn or actually connected together so that there are more than two points in the circuit. In Figure 2, resistors $R_2$ and $R_3$ are connected together first to form points C and D before they are connected to the rest of the parallel circuit at points A and B.

In Figure 2 the currents in each of the resistors and the total current are the same as they are in Figure 1. The voltage in each circuit is also the same.

The only difference between the two circuits is that extra current paths have been made between points A and D and between B and C. If you measured the current in each of these extra wires you would measure the sum of the currents in $R_2$ and $R_3$ or $I_2 + I_3$.

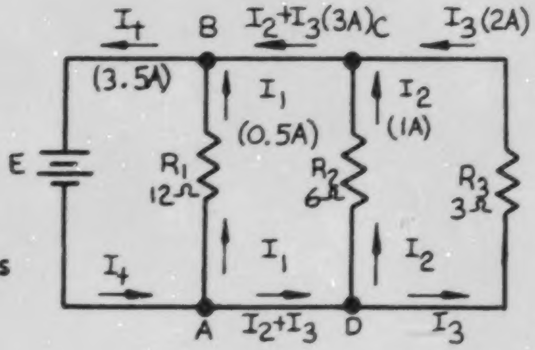


Figure 2

In other words, connecting the parallel circuit in this way divides the total current from the source in stages rather than all at once. First $I_1$ is subtracted from $I_t$ at point A. What is left is $I_t - I_1$ which also equals $I_2 + I_3$.

This remaining current divides at point D into the separate currents $I_2$ and $I_3$.

In equation form,

$I_t = I_1 + I_2 + I_3$

$I_t - I_1 = I_1 + I_2 + I_3 - I_1$ subtracting $I_1$ from both sides of the equation

$I_t - I_1 = I_2 + I_3$ cancelling the $I_1$ terms

$3.5A - 0.5A = 1A + 2A$ for the values of Figure 2

$3A = 3A$

Of course the currents add back together in stages, first at point C to form $I_2 + I_3$ and finally at point B to form $I_1 + I_2 + I_3$ which equals $I_t$.

If it makes it easier for you to work only with the parallel circuit drawn as in Figure 1, it is all right to redraw Figure 2 so that it looks like Figure 1. Just combine points A and D into a single point, and combine points B and C into a single point.

In Figures 1 and 2 suppose you were not told that the voltage was 6 volts, and that all you were told was the value of each resistor and the total current of 3.5A. You can solve for the voltage by knowing how resistors combine in parallel. But before you do that, you should know what conductance is. Conductance is the exact opposite of resistance.

A resistor with a large value of resistance has a small value of conductance, and a resistor with a small value of resistance has a large value of conductance. Conductance is the property of a component to allow or to accept current from a source, but resistance is the property to oppose or to restrict current flow. The symbol for conductance is G and mathematically, $G = \frac{1}{R}$.

For a resistor with a value of resistance equal to R ohms, its conductance G is one divided by the value of R. That is the same as saying that conductance is the reciprocal of resistance. Likewise resistance is the reciprocal of conductance. Review the package on Equations if you are having trouble understanding reciprocals. The unit for conductance is the mho. More recently the unit has been changed to the Sieman or just S, but many people continue to use the mho since it is ohm written backwards. The mho is abbreviated by the ohm symbol written upside down ℧. For the three resistors in Figure 1 or 2:

$G_1 = \frac{1}{R_1} \qquad G_2 = \frac{1}{R_2} \qquad G_3 = \frac{1}{R_3}$ and $R_1 = 12\Omega,\ R_2 = 6\Omega,\ R_3 = 3\Omega$

$G_1 = \frac{1}{12\Omega} \qquad G_2 = \frac{1}{6\Omega} \qquad G_3 = \frac{1}{3\Omega}$

$G_1 = 0.083℧ \qquad G_2 = 0.167℧ \qquad G_3 = 0.333℧$

Going back to the original problem, given the resistances and the total current, solve for the voltage. First combine the parallel resistors into one equivalent or total resistance. For parallel resistors you add their conductances.

CONDUCTANCE IN PARALLEL ADDS

Placing additional components in parallel adds to the total current and increases the conductance of the total circuit. Two resistors of equal value placed in parallel across a voltage source will draw twice the current as either one alone, and the total conductance will be twice the conductance of either one.

In equation form, $G_t = G_1 + G_2 + G_3$ and so on for parallel resistors.

In Figures 1 and 2:

$G_t = 0.083\mho + 0.167\mho + 0.333\mho$

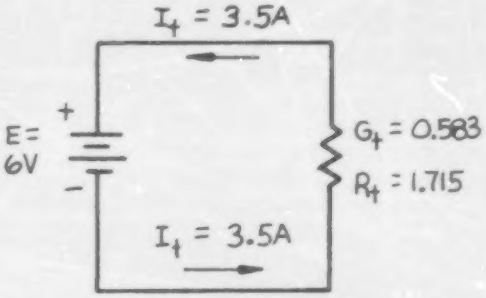
$G_t = 0.583\mho$

$R_t = \frac{1}{G_t}$

$R_t = \frac{1}{0.583\mho}$

$R_t = 1.715\Omega$

Since the values for $G_1$, $G_2$, and $G_3$ were already calculated as 0.083, 0.167, and 0.333℧.



Equivalent Circuit of Figures 1 and 2

FIGURE 3

The total or equivalent resistance of resistors in parallel is always LESS THAN the resistance of any one of the resistors. It is therefore always smaller than the smallest one. Notice that 1.715Ω is less than the smallest resistance of 3Ω. Figure 3 is an equivalent circuit for both Figures 1 and 2. The voltage can now be solved by applying ohm's law to the equivalent circuit.

$E = I_t \times R_t$

$E = 3.5A \times 1.715\Omega$

$E = 6$ volts

EXAMPLE 1: Four resistors are in parallel and the total current is 44.4 mA.

$G_t = G_1 + G_2 + G_3 + G_4$

$R_1 = 1k,\ R_2 = 2k,\ R_3 = 5k,\ R_4 = 0.5k,\ I_t = 44.4mA$

$G_t = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

Calculate $R_t$ and E

$G_t = \frac{1}{1k} + \frac{1}{2k} + \frac{1}{5k} + \frac{1}{0.5k}$

remember $k = 1000$; $m = 0.001$; and $m = \frac{1}{k}$

$G_t = 0.001 + 0.0005 + 0.0002 + 0.002\mho$

Also $G_t = 1m + 0.5m + 0.2m + 2m\mho$

$G_t = 0.0037\mho$ or $3.7\ m\mho$

$R_t = \frac{1}{G_t} = 270\Omega$ or $0.27k\Omega$

$E = I_t \times R_t$

$E = 0.044A \times 270\Omega$

also $E = 44.4\ mA \times 0.27k$

$E = 12$ volts

$E = 12$ volts since $k \times m = 1$

You can double check Kirchhoff's Current Law by calculating the currents in each resistor using Ohm's law.

$$I_1 = \frac{E}{R_1} \qquad I_2 = \frac{E}{R_2} \qquad I_3 = \frac{E}{R_3} \qquad I_4 = \frac{E}{R_4}$$

$$I_1 = \frac{12V}{1k} \qquad I_2 = \frac{12V}{2k} \qquad I_3 = \frac{12V}{5k} \qquad I_4 = \frac{12V}{0.5k}$$

$$I_1 = 12mA \qquad I_2 = 6mA \qquad I_3 = 2.4mA \qquad I_4 = 24mA$$

$I_t = I_1 + I_2 + I_3 + I_4$

$I_t = 12 + 6 + 2.4 + 24mA$

$I_t = 44.4mA$

If the source voltage were known instead of the source current, you could solve the problem in the same way, and divide E by $R_t$ (or multiply E by $G_t$) to find $I_t$. Instead, you could solve for each of the individual resistor currents directly and add them to find $I_t$.

That is $I_1 = \frac{E}{R_1}$, $I_2 = \frac{E}{R_2}$ and so on.

If you are finding the equivalent resistance of two resistances only, an alternate formula can be used.

$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$ for two resistances.

In words the formula states that the total or equivalent resistance of two resistors in parallel is the product of the two resistances divided by the sum of the two resistances.

Actually you can use this formula when there are more than two resistors if you combine the resistances in stages two at a time. Examples 3 and 4 will show how this is done.

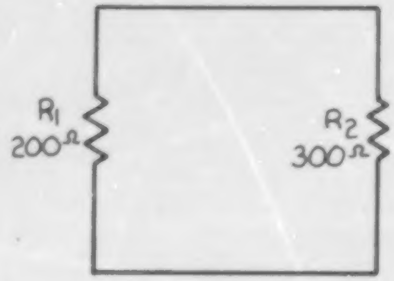
EXAMPLE 2: Find $R_t$

$$R_t = \frac{R_1 \text{ X } R_2}{R_1 + R_2}$$

$$R_t = \frac{200 \text{ X } 300}{200 + 300}\ \Omega$$

$$R_t = \frac{60000}{500}\ \Omega$$

$$R_t = 1200\ \Omega$$



EXAMPLE 3: Find $R_t$

$$R_{t_1} = \frac{R_2 \text{ X } R_3}{R_2 + R_3}$$

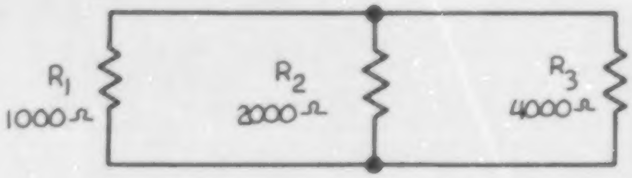
$$R_{t_1} = \frac{2000 \text{ X } 4000}{2000 + 4000}\ \Omega$$

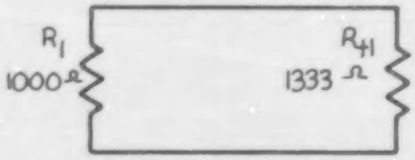
$$R_{t_1} = 1333\ \Omega$$

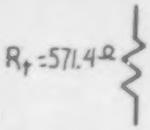
$$R_t = \frac{R_1 \text{ X } R_{t_1}}{R_1 + R_{t_1}}$$

$$R_t = \frac{1000 \text{ X } 1333}{1000 + 1333}\ \Omega$$

$$R_t = 571.4\ \Omega$$

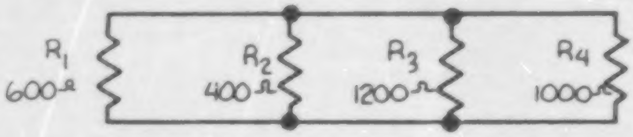






EXAMPLE 4:

Find $R_t$. Two different ways of combining resistors two at a time are shown as well as the method using conductances. Compare the methods to see which you prefer. It doesn't matter which two resistors you combine first. Method 1 and method 2 are different only because different resistors are combined first. Method 3 combines conductances.



Method 1

$$R_{t_1}=\frac{R_1 X R_2}{R_1+R_2} \qquad R_{t_2}=\frac{R_3 X R_4}{R_3+R_4}$$

$$R_{t_1}=\frac{600X400}{600+400} \qquad R_{t_2}=\frac{1200X1000}{1200+1000}$$

$$R_{t_1}=240\Omega \qquad R_{t_2}=545.5\Omega$$

$$R_t=\frac{R_{t_1} X R_{t_2}}{R_{t_1}+R_{t_2}}$$

$$R_t=\frac{240X545.5}{240+545.5}$$

$$R_t = 166.7\ \Omega$$

Method 2

$$R_{t_1}=\frac{R_1 X R_4}{R_1+R_4} \qquad R_{t_2}=\frac{R_2 X R_3}{R_2+R_3}$$

$$R_{t_1}=\frac{600X1000}{600+1000} \qquad R_{t_2}=\frac{400X1200}{400+1200}$$

$$R_{t_1}=375\Omega \qquad R_{t_2}=300\Omega$$

$$R_t=\frac{R_{t_1} X R_{t_2}}{R_{t_1}+R_{t_2}}$$

$$R_t=\frac{375X300}{375+300}$$

$$R_t=166.7\Omega$$

Method 3

$$G_t=G_1+G_2+G_3+G_4$$

$$G_t=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}$$

$$G_t=\frac{1}{600}+\frac{1}{400}+\frac{1}{1200}+\frac{1}{1000}$$

$$G_t=0.00167+0.0025+0.00083+0.001$$

$$G_t=0.006\mho$$

$$R_t=\frac{1}{G_t}=166.7\Omega$$

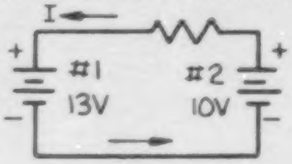
Batteries are generally NOT connected in parallel. If two batteries are placed in parallel, plus side to plus side and minus side to minus side, usually one battery will be supplying power, and the other will be absorbing power. A very large current will flow if the batteries do not have the same voltage. The same is true for other voltage sources.

A battery that is absorbing power is being charged.

This can cause damage to the batteries unless done under controlled conditions which include the following:

1. Charging only rechargeable type batteries.
2. Observing proper polarity.
3. Manually or automatically controlling the current that flows.

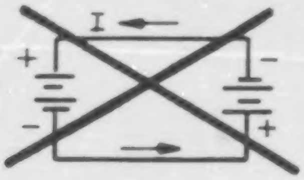
Small resistance to limit current



Battery #2 is being charged

The battery with the smaller voltage is being charged. If it is rechargeable, its voltage will increase, and the voltage of the battery supplying power will decrease. Charging will stop (zero current) when the two battery voltages are the same.

If the two batteries are placed in parallel, plus side to minus side and minus side to plus side, both batteries will be short circuited by each other. This will cause excessive current, and it will destroy the batteries.



Excessive current flows

Batteries Shorted and Damaged

REVIEW OF FORMULAS FOR PARALLEL CIRCUITS

$$G = \frac{1}{R}$$

$$G_t = G_1 + G_2 + G_3 + G_4 + \text{and so on}$$

$$G_t = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{and so on}$$

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2} \text{ for two resistors in parallel}$$

## Self-Test

1. Two or more resistors in parallel have the same

   a. voltage. b. current. c. power. d. value.

2. To find the equivalent value of resistors in parallel the resistances must be

   a. added. b. subtracted. c. added then inverted.
   d. inverted then added and the result inverted.

3. The equivalent value of parallel resistors is

   a. smaller than b. larger than c. equal to d. twice
   the value of the smallest resistance.

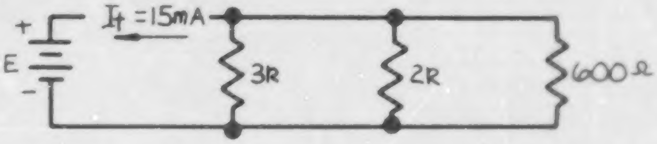
4. A 600 ohm and a 300 ohm resistor are in parallel. The total resistance is

   a. 900 ohms. b. 300 ohms. c. 200 ohms. d. 0.005 ohm.

5. Four resistors are in parallel, a 1k, 2k, and two 4k's. $R_t$ is

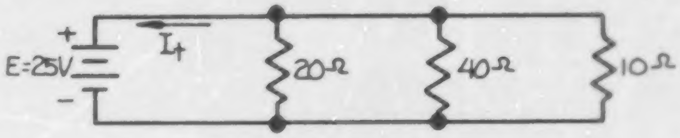
   a. 571 ohms. b. 500 ohms. c. 11k. d. 1k.

6. Solve for the voltage E



   E = __________V

7. Solve for $I_t$ and $R_t$



   $I_t$ = __________

   $R_t$ = __________

8. Five resistors are in parallel. $R_1 = 2k$, $R_2 = 3k$, $R_3 = 10k$, $R_4 = 5k$ and $R_5 = 100\ \Omega$. Calculate the equivalent resistance $R_t$.

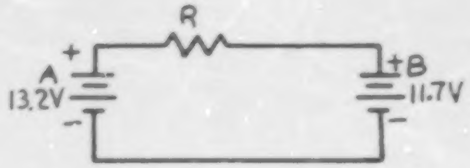
   $R_t$ = __________

9. Batteries can be placed in parallel without danger or damage to the batteries

   a. no matter how they are connected.
   b. if the one that is charging is properly connected and is a rechargeable type.
   c. under no circumstances.

10. The total resistance of three parallel resistors is 100 ohms. One of the resistors is 200 ohms and another is 400 ohms. Find the third value. Use the conductance method.

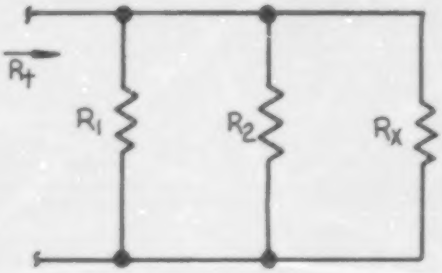
    $R_3$ = __________



11. Which battery is being charged (absorbing energy)?

12. Determine the value of the unknown resistance $R_x$.

    $R_1 = 15\ \Omega$
    $R_2 = 10\ \Omega$
    $R_t = 5\ \Omega$



## Task

Given a power supply and the following resistors connected in parallel, 2.7k, 3.3k, 4.7k, and 8.2k. Measure the supply voltage with the voltmeter. Calculate the equivalent value of resistance.

Calculate the value of current that will flow when the supply is connected. Use the measured value of supply voltage.

Calculate the current that will flow in each resistor.

Connect the circuit using the interconnecting leads, and alternately connect the ammeter in series with each resistor. In this way measure the current in each of the resistors. See the Figure.

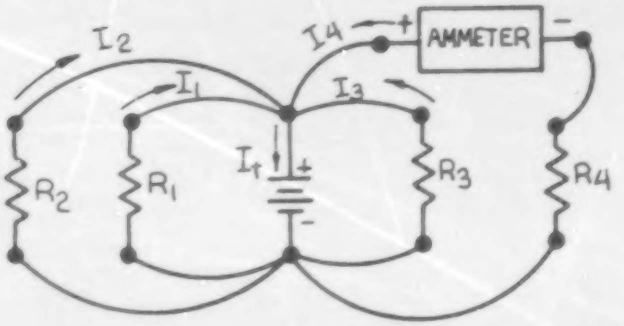
Also connect the ammeter in series with the supply to measure the total current. See the Figure.

Obtain a single resistor of value equal to the value calculated for the total resistance. Connect this resistor alone with the ammeter and the supply all together in SERIES and measure the current. See the Figure.

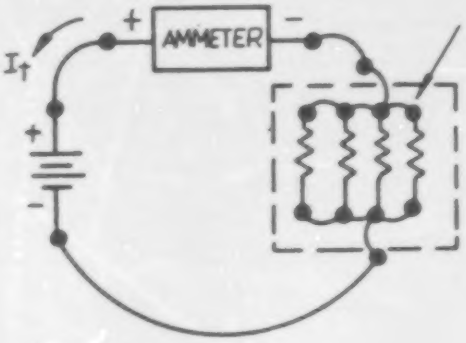
The current measured with each single resistor should equal the total current measured for the original circuit. It should also equal the calculated value for total current.

Also the calculated and measured values of individual resistor currents should be the same. The following are reasons why any of them may differ:

1. The meter causes errors in measurement.
2. The actual and printed values of the parts may differ.
3. You may have made an error in calculation or measurement. Have your instructor check your results.



Ammeter Connection to Measure $I_4$



Ammeter Connection to measure $I_t$

## Final Test

1. When electrical components are connected in parallel, the voltage across each and every component will be

   a. zero. b. equal to the current. c. different from each other.
   d. the same as each other.

2. To combine parallel resistances you add

   a. conductances. b. resistances. c. voltages.

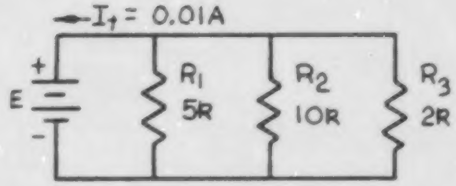
3. The equivalent value of resistances in parallel will always be less than the

   a. largest resistance. b. smallest resistance.
   c. largest plus smallest resistances.

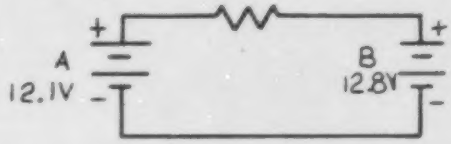
4. Four resistors are connected in parallel. $R_1 = 100\Omega$, $R_2 = 150\Omega$, $R_3 = 50\Omega$, and $R_4 = 200\Omega$. Calculate the total resistance $R_t$.

5. The equivalent resistance of three resistors in parallel is $R_t = 500$. One of the resistors is 1k and another is 2k. Find the value of the third. Use the method of conductances.

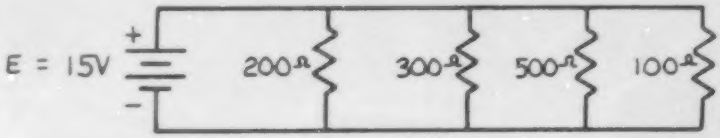
6. Solve for the voltage in the circuit.



7. Which battery, A or B is being charged? What limits the current from charging too fast?



8. Solve for $I_t$ and $R_t$.



## Answers

1. a. Voltage.
2. d. inverted then added and the result inverted.
3. a. smaller than
4. c. 200 ohms.
5. b. 500 ohms.
6. 6 volts.
7. 4.375 A.
8. $R_t = 89.82\Omega$.
9. b. if the one that is charging properly connected and is a rechargeable type.
10. 400Ω also $G_3 = G_t - G_1 - G_2$

    $G_3 = .01 - .005 - .0025\ \mho$

    $G_3 = .0025\ \mho$

    $R_3 = \frac{1}{G_3}$

    $R_3 = \frac{1}{.0025}$

    $R_3 = 400\Omega$
11. Battery B (11.7V) is being charged.
12. $R_x = 30\Omega$; $G_t = G_1 + G_2 + G_x$, $G_t = \frac{1}{5}\mho$, $G_1 = \frac{1}{15}\mho$, $G_2 = \frac{1}{10}\mho$

    $G_x = G_t - G_1 - G_2$, $G_t = 0.2\mho$, $G_1 = 0.0667\mho$, $G_2 = 0.1\mho$

    $G_x = 0.2 - 0.0667 - 0.1\mho$

    $G_x = 0.0333\mho$

    $R_x = \frac{1}{G_x}$

    $R_x = \frac{1}{0.0333}\ \Omega$

    $R_x = 30\ \Omega$

## Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Calculated Resistance | | |
| Calculated Currents | | |
| Measured Resistor Currents | | |
| Measured Total Current | | |
| Current Measured in Equivalent Circuit | | |
| Final Test | | |

When all of the checks indicate OK, proceed to the next learning package.

# 2.14

## SERIES-PARALLEL RESISTIVE CIRCUITS

## Goal:

The apprentice will be able to calculate current and resistance in a series-parallel combination circuit.

## Performance Indicators:

1. Calculate resistance.
2. Calculate current.
3. Measure current with ammeter.

# BASIC ELECTRONICS

# Series-Parallel Resistive Circuits
## EL-BE-22

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| A voltage source and resistors arranged in series-parallel combinations | Calculate the equivalent value of resistance for the series-parallel combination. |
| A voltmeter and ammeter or combination voltmeter-ammeter | Calculate the current drawn by the circuit with the source connected. |
| | Measure the current with the ammeter. |
| | Measure the current with the circuit replaced by the equivalent resistor. |
| Questions and problems | Complete a Final Test with an accuracy of 85%. |

## Directions

Obtain the following:

A DC power supply

Resistors 1/4 watt, 2%
330, 470, 1k, 1.8k, 2.2k, 2.7k, 3.3k, 4.7k, ohms

A DC voltmeter and ammeter (or combination meter)

Interconnecting wires or leads

## Learning Activities

______ Study the Key Words list.

______ Read the Information Sheets.

______ Do the Self-Test.

______ Do the Task.

______ Take the Final Test.

______ Obtain Final Evaluation.

## Key Words

Kirchoff's Voltage Law: The law that states that voltages add in series or that the sum of the voltages around a closed path is zero.

Kirchoff's Current Law: The law that states that currents add in parallel or that the sum of the currents entering and leaving a point is zero.

$E_{AB}$: A symbol to represent the voltage between points A and B in a circuit.

Series connection of components: A method of connecting electrical components so that one end but only one end of each component is connected to each of the other components; series components always have the same current.

Parallel connection of components: A method of connecting electrical components so that they are connected between or across the same two points in a circuit; parallel components always have the same voltage.

# Information Sheet

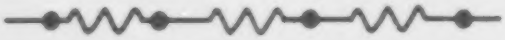
Most circuits are connected so that there are both series and parallel combinations of resistors. The circuits can be simplified by combining either series combinations or parallel combinations of resistors. Usually the combination of either series or parallel resistors will change the circuit in such a way that additional series or parallel combinations result. The circuit can then be further simplified, and the original complicated circuit can be reduced to a simpler one by a series of repeated combinations of resistors.

Using the process of repeated series and parallel combinations just described, we can often reduce the circuit to an equivalent circuit of only a single resistor. The important thing to learn is how to determine which resistors, if any, are actually in series or which, if any, are in parallel. You must be careful not to combine resistors that are not actually in series or in parallel.

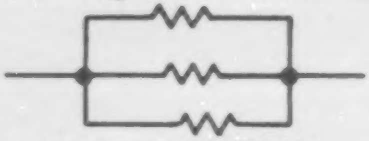
It should be helpful to you to review the packages on series and on parallel resistive circuits to remind you how components are connected in series or in parallel. It may also be helpful to go all the way back to the package "Introduction to Circuits" in which series and parallel connections of components were first defined.

Before an example is worked, the rules for series and parallel connections are restated.

Series connection--components are in series if they are connected end to end such that one and only one end of each component is connected to another component. Another way to identify series components is to look for components with the same circuit current. Components in series will always have the same circuit current.


SERIES CONNECTION

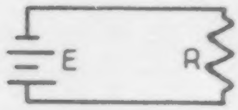
Parallel connection--components are in parallel if they are connected between or across the same two voltage points in a circuit. Another way to identify parallel components is to look for components with the same circuit voltage. Components in parallel will always have the same circuit voltage.


PARALLEL CONNECTION

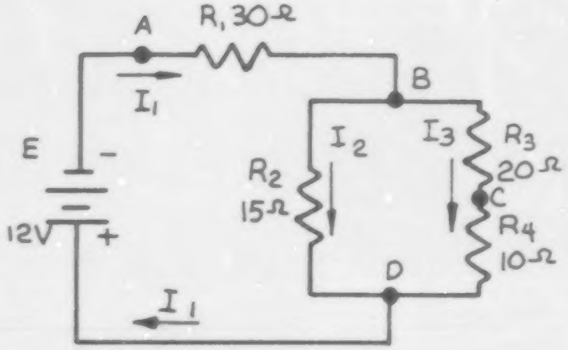
A special case occurs when there are only two components in the circuit. The two components are both in series and in parallel since they have the same current and the same voltage.

Here are some examples to help you recognize series and parallel combinations. In the figure, which resistors are in series and which resistors are in parallel? $R_3$ and $R_4$ are in series. They both have the same current, $I_3$, flowing in them.

E and R are both in series and in parallel.



There are NO resistors in parallel. No two resistors are connected between the same two points in the circuit. $R_1$ is between points A and B, $R_2$ between B and D, $R_3$ between B and C, and $R_4$ between C and D. The source E is between points A and D. All four points are separate points and cannot be combined since each is separated by at least one component rather than a wire connection. So the only thing you can do is to combine $R_3$ and $R_4$ into one equivalent resistor which could be called $R_x$, and redraw the circuit.

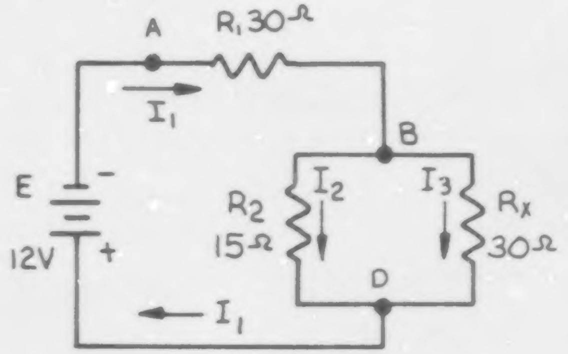


$$R_x = R_3 + R_4$$

$$R_x = 20 + 10\Omega$$

$$R_x = 30\Omega$$

Notice that point C is eliminated when the equivalent circuit is drawn. Notice also that combining $R_3$ and $R_4$ into a single resistor has resulted in the parallel combination of two resistors $R_2$ and the new resistance $R_x$. $R_2$ and $R_x$ are both between the points B and D and are in parallel. No two resistors are in series anymore.



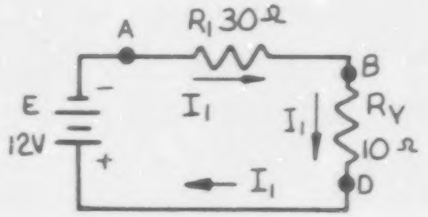
Equivalent Circuit 1

Now you can combine $R_2$ and $R_x$ into a single equivalent resistance; call it $R_y$ and redraw the circuit.

$$R_y = \frac{R_2 \times R_x}{R_2 + R_x}$$

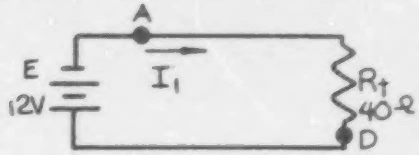
$$R_y = \frac{15 \times 30}{15 + 30}\ \Omega$$

$$R_y = 10\Omega$$



Equivalent Circuit 2

In the second equivalent circuit, the only two resistors left are in series. Combining those two into one final total resistance for the entire circuit, $R_t$, you have



Final Equivalent Circuit

$R_t = R_1 + R_y$

$R_t = 30 + 10\Omega$

$R_t = 40\Omega$

Now that $R_t$ has been determined, $I_1$ can be found.

$I_1 = \frac{E}{R_t}$

$I_1 = \frac{12V}{40\Omega}$

$I_1 = 0.3A$

You can solve for all of the other currents and voltages in the original circuit by going back to the other equivalent circuits. Using equivalent circuit 2,

the voltage across $R_1 = E_{AB} = I_1 x R_1$ and the voltage across $R_2 = E_{BD} = I_1 x R_y$

$E_{AB} = 0.3A x 30\Omega$ $E_{BD} = 0.3A x 10\Omega$

$E_{AB} = 9$ volts $E_{BD} = 3$ volts

Notice that $E_{AB} + E_{BD} = E_{AD} = E$ Kirchhoff's Voltage Law

$9V + 3V = 12V$

Going back to equivalent circuit 1,

$I_2 = \frac{E_{BD}}{R_2}$ and $I_3 = \frac{E_{BD}}{R_x}$ but $E_{BD}$ has been found

to be 3V so $I_2 = \frac{3V}{15\Omega}$ and $I_3 = \frac{3V}{30\Omega}$

$I_2 = 0.2A$ $I_3 = 0.1A$

Notice that $I_2 + I_3 = I_1$ Kirchhoff's Current Law

$0.2A + 0.1A = 0.3A$

Finally, using the original circuit,

the voltage across $R_3 = E_{BC} = I_3 \times R_3$ and across $R_4$, $E_{CD} = I_3 \times R_4$

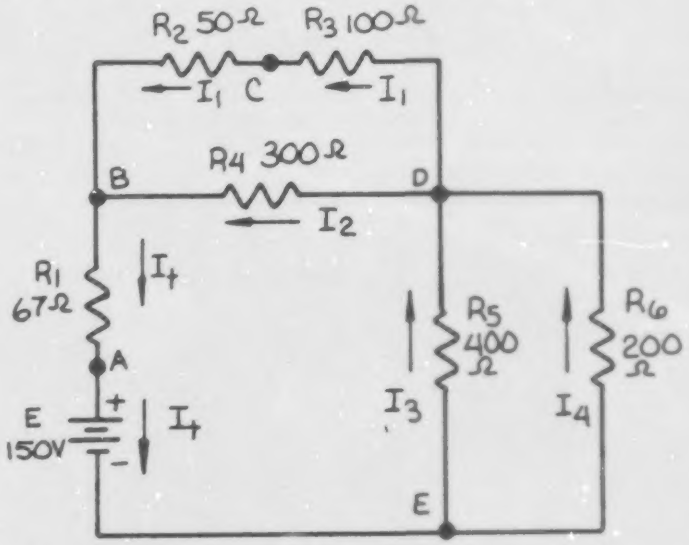
$$E_{BC} = 0.1A \times 20\Omega \qquad E_{CD} = 0.1A \times 10\Omega$$

$$E_{BC} = 2V \qquad E_{CD} = 1V$$

Notice that $E_{BC} + E_{CD} = E_{BD}$ Kirchhoff's Voltage Law

$$2V + 1V = 3V$$

Finally, all of the currents and voltages have been found, and Kirchoff's Laws have been used as a double check.


R2 50Ω
R3 100Ω
I1
C
I1
B
R4 300Ω
D
I2
R1
67Ω
It
A
R5
400
Ω
R6
200
Ω
E
150V
+
−
It
I3
I4
E

Example:

Find $R_t$ and solve for all of the currents and voltages in the circuit. Which resistors are in series? Only $R_2$ and $R_3$, so $R_x = R_2 + R_3$

$$R_x = 50 + 100$$

$$R_x = 150\Omega$$

Which resistors are in parallel?

Only $R_5$ and $R_6$, so $R_y = \frac{R_5 \times R_6}{R_5 + R_6}$

$$R_y = \frac{400 \times 200}{400 + 200}$$

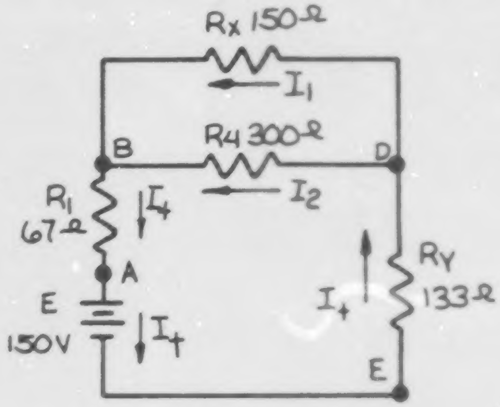
$$R_y = 133\Omega$$

In equivalent circuit 1, $R_x$ and $R_4$ are in parallel.

$$R_z = \frac{R_x \times R_4}{R_x + R_4}$$

$$R_z = \frac{150 \times 300}{150 + 300}$$

$$R_z = 100\Omega$$


Rx 150Ω
I1
B
R4 300Ω
D
R1
67Ω
It
I2
A
RY
133Ω
E
150V
It
It
E

Equivalent Circuit 1

Finally $R_1$, $R_z$ and $R_y$ are in series so that $R_t = R_1 + R_z + R_y$

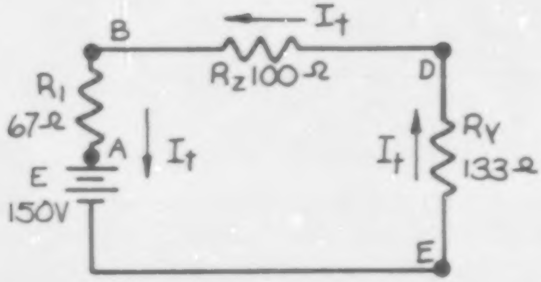
$R_t = 67 + 100 + 133\Omega$

$R_t = 300\Omega$

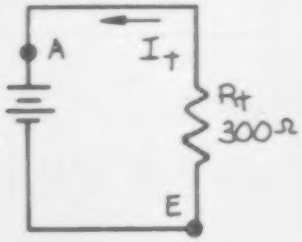
$I_t = \frac{E}{R_t}$

$I_t = \frac{150V}{300\Omega}$

$I_t = 0.5A$



Equivalent Circuit 2



Final Equivalent Circuit

---

$E_{AB} = I_t \times R_1$

$E_{AB} = 0.5A \times 67\Omega$

$E_{AB} = 33V$

$E_{BD} = I_t \times R_z$

$E_{BD} = 0.5A \times 100\Omega$

$E_{BD} = 50V$

$E_{DE} = I_t \times R_y$

$E_{DE} = 0.5A \times 133\Omega$

$E_{DE} = 67V$

---

$I_1 = \frac{E_{BD}}{R_x}$

$I_1 = \frac{50V}{150\Omega}$

$I_1 = 0.33A$

$I_2 = \frac{E_{BD}}{R_4}$

$I_2 = \frac{50V}{300\Omega}$

$I_2 = 0.167A$

$I_3 = \frac{E_{DE}}{R_5}$

$I_3 = \frac{67V}{400\Omega}$

$I_3 = 0.1675A$

$I_4 = \frac{E_{DE}}{R_6}$

$I_4 = \frac{67V}{200\Omega}$

$I_4 = 0.335A$

---

$E_{BC} = I_1 \times R_2$

$E_{BC} = 0.33A \times 50\Omega$

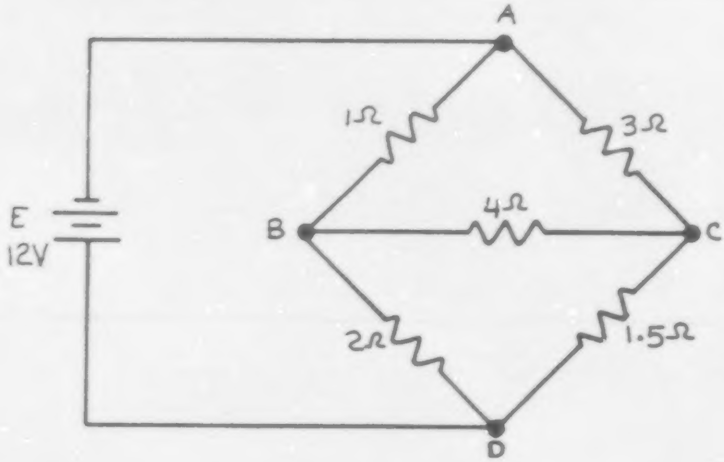
$E_{BC} = 16.5V$

$E_{CD} = I_1 \times R_3$

$E_{CD} = 0.33A \times 100\Omega$

$E_{CD} = 33V$

It was already stated that some circuits do not have any combinations of resistors that are either in series or in parallel. These circuits cannot be simplified by the method presented here. One example of such a circuit is the bridge circuit. Notice that no two resistors are either in series or in parallel. Each of the resistors and the source is between a different set of points in the circuit. Also there is a different current in each resistor and the source since the current divides at each of the points, A, B, C, and D. Methods used to calculate the voltages and currents are a subject for a more advanced course in electronics.



BRIDGE CIRCUIT

| Component | Between Points |
|---|---|
| 1Ω resistor | A & B |
| 3Ω resistor | A & C |
| source | A & D |
| 4Ω resistor | B & C |
| 2Ω resistor | B & D |
| 1.5Ω resistor | C & D |

Power in a series-parallel resistive circuit is calculated in the same way as it is in less complicated circuits.

The total power supplied by sources equals the total power absorbed by resistors (or other sources if they are charging).

The power absorbed for each resistor is calculated once you have determined either the current or voltage for the resistor.

| | | |
|---|---|---|
| Using the resistor current | $P = I^2 \times R$ | |
| Using the resistor voltage | $P = \frac{E^2}{R}$ | All three formulas give the same answer. |
| Using both current and voltage for the resistor | $P = E \times I$ | |

The power supplied by a source is calculated by the formula

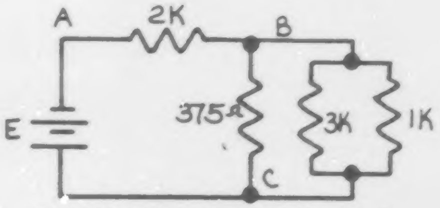
$$P = E \times I$$

where E and I are the values of voltage and current for the source. If the current is leaving the plus (+) terminal of the source instead of the minus (-) terminal, the formula gives the power absorbed by the source.

## Self-Test

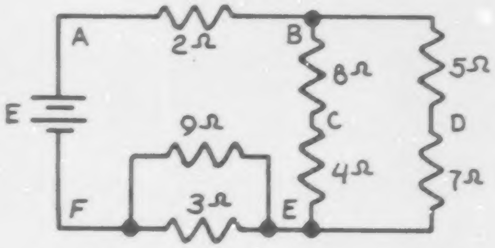
For the circuits in questions 3-11, it will probably be helpful to assign letter labels to each of the separate points as was done in the examples. What may look like two different points will be the same point if they are connected by a piece of wire. Also two resistors may be connected together without drawing a connecting dot, but a connection is nevertheless made so that a letter should be assigned to that connection or point. Draw your own dot if it is helpful. Letter labels are already assigned for the first two figures in order to help you understand the procedure.

1. Series resistors always have the same
    - a. voltage.
    - b. current.
    - c. power.
    - d. resistance value.
2. Parallel resistors always have the same
    - a. voltage.
    - b. current.
    - c. power.
    - d. resistance value.
3. Determine which, if any, resistors are in series and find the equivalent value.
4. Determine which resistors, if any, are in parallel and find their equivalent value.
5. Solve for the total equivalent resistance for the circuit in questions 3 and 4.



Circuit for Questions 3-5

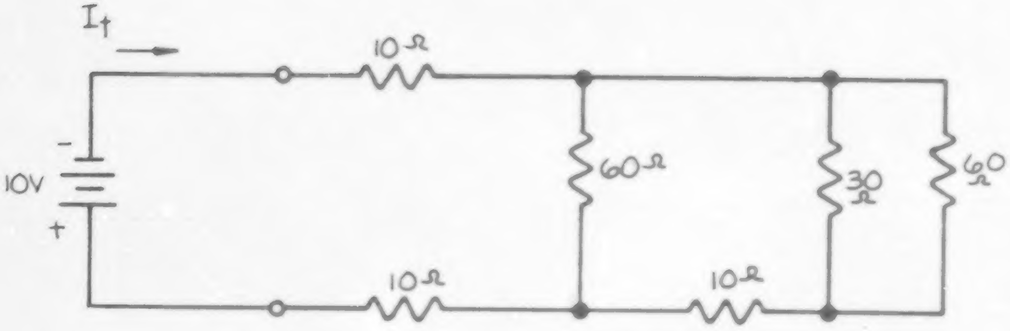
6. Determine which resistors, if any, are in series and find the equivalent value.
7. Determine which resistors, if any, are in parallel and find their equivalent value.
8. Solve for the total equivalent resistance for the circuit in questions 6 and 7.



Circuit for Questions 6-8

(Circuit for questions 9-11 on following page.)

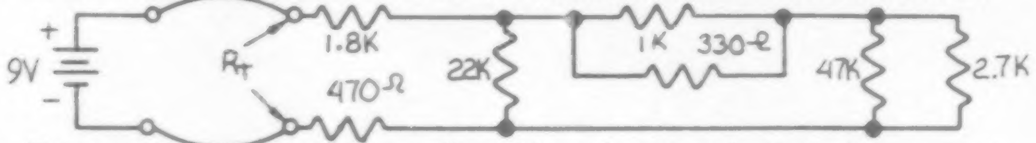
9. Solve for the equivalent value of resistance for the total circuit $(R_t)$.
10. Solve for the currents and voltages in each of the resistors.
11. Solve for the power supplied by the source.


$I_t$
10Ω
10V
-
+
60Ω
30Ω
60Ω
10Ω
10Ω

Circuit for Questions 9-11

## Task

1. Calculate the equivalent value of resistance for the circuit shown.



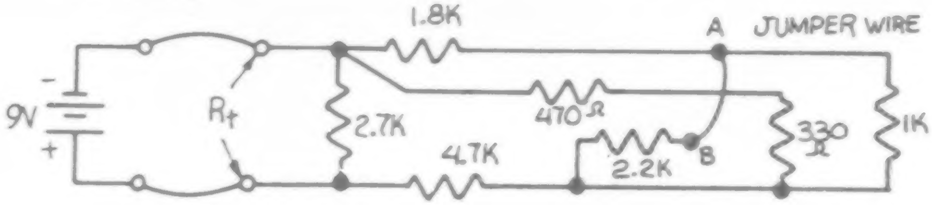
2. Measure the source voltage. Use this value to calculate the current drawn from the source with the circuit connected.

3. Check with your instructor that you have calculated the correct values. Then get a single resistor equal in value to the calculated circuit value.

4. Connect the circuit and measure the current with the ammeter. Connect also the single resistor alone and measure the current with the ammeter.

5. All three currents should be close to the same value. If your resistors were low-tolerance types, the results could be considerably off. Check with your instructor to determine how well you did.

6. Calculate the equivalent value of resistance for the re-arranged circuit as shown.



Connect a jumper wire between points A and B as shown.

7. Calculate the current when a 9 volt source is connected to the circuit.

8. Connect the complete circuit and measure the current.

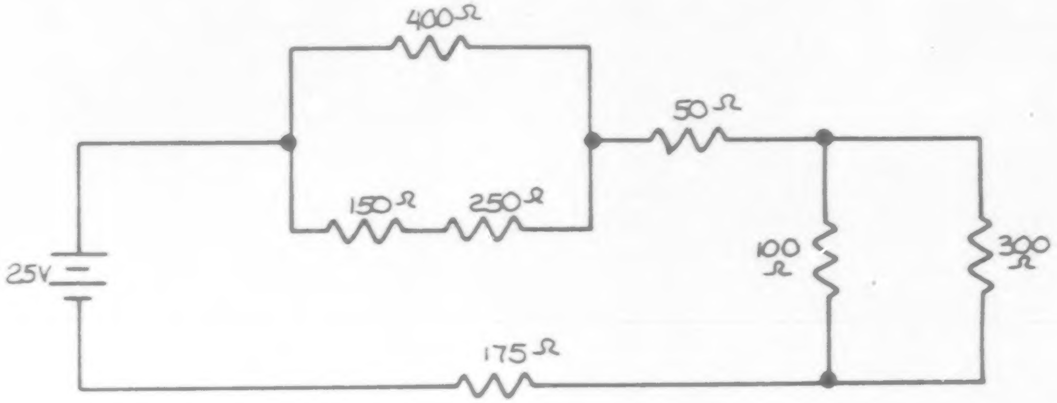
9. Connect a single resistor of equivalent value as calculated and measure the current in the single resistor with the ammeter.

10. Have your instructor check your calculated and measured results.

*Points A and B are indicated as separate points only to indicate where to attach an interconnecting wire or jumper. When this jumper is connected, the two points become the same point in the circuit. The circuit can be drawn a different way by placing the 2.2k resistor to the right of the 1k resistor, but an interconnecting jumper is still needed. In both cases the 2.2k and 1k resistors are in parallel and connected between the same two points in the circuit.

# Final Test

1. Determine which resistors, if any, are in series.
2. Determine which resistors, if any, are in parallel.
3. Solve for the total equivalent resistance.
4. Solve for the currents and voltages in each of the components.
5. Solve for the power supplied by the source.


400Ω
50Ω
150Ω
250Ω
25V
100 Ω
300 Ω
175Ω

# Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Calculated Resistance | ________ | ________ |
| Calculated Current | ________ | ________ |
| Measured Current | ________ | ________ |
| Current Measured in Equivalent Resistor | ________ | ________ |
| Final Test 85% | ________ | ________ |

When all of the checks indicate OK, proceed to the next learning package.

## Answers

1. b. current.
2. a. voltage.
3. No resistors are in series.
4. 375Ω, 3k, and 1k are all in parallel. All are between points B and C.

$$G = \frac{1}{375} + \frac{1}{3000} + \frac{1}{1000} = 0.004\mho$$

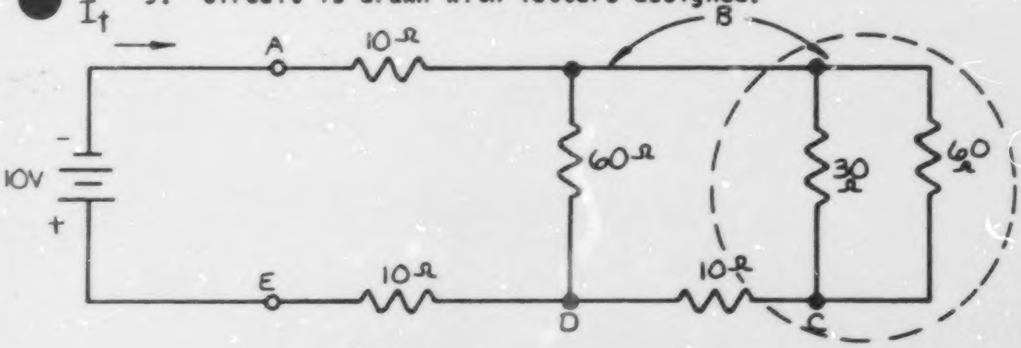
MHO--(℧)
(inverted ohm--Ω)

$$R = \frac{1}{G} = \frac{1}{0.004} = 250\Omega$$ equivalent value

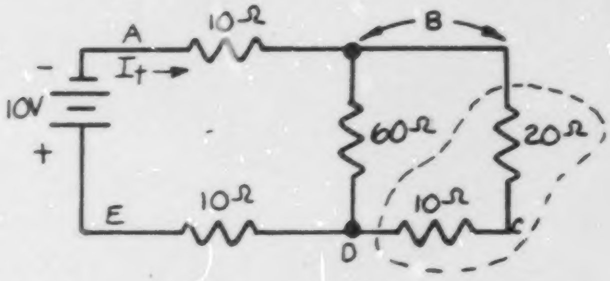
5. 2k and 250Ω are in series equalling 2000 + 250 = 2250Ω
6. 8Ω and 4Ω are in series equalling 8 + 4 = 12Ω

   5Ω and 7Ω are in series equalling 5 + 7 = 12Ω
7. 9Ω and 3Ω are in parallel equalling $\frac{9 \times 3}{9 + 3} = 2.25\Omega$
8. 12Ω and 12Ω are in parallel equalling 6Ω

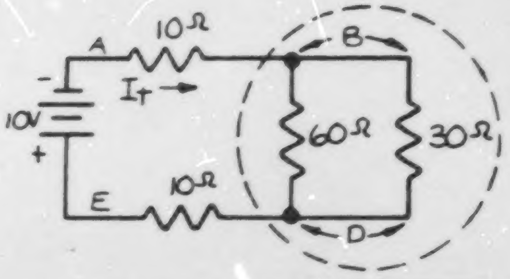
   2Ω, 6Ω, and 2.25Ω are in series equalling 10.25Ω
9. Circuit is drawn with letters assigned.


$I_t$
A
10Ω
B
10V
-
+
60Ω
30Ω
60Ω
E
10Ω
D
10Ω
C

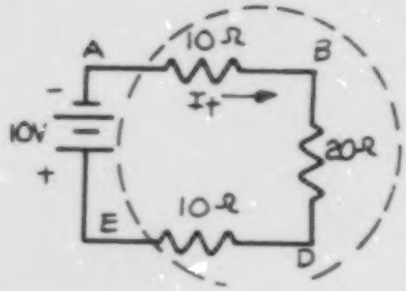
in parallel
between points
B and C


A
10Ω
B
$I_t$
10V
-
+
60Ω
20Ω
E
10Ω
D
10Ω
C

in series, point C
is eliminated when
combined


A
10Ω
B
$I_t$
10V
-
+
60Ω
30Ω
E
10Ω
D

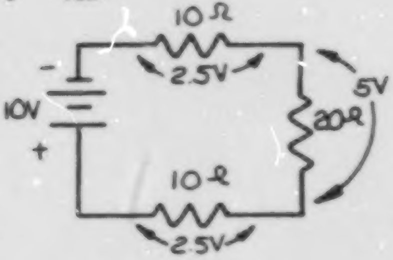
in parallel between
points B and D


A
10Ω
B
$I_t$
-
10V
+
20Ω
10Ω
E
D

in series $R_t = 10 + 20 + 10\Omega$

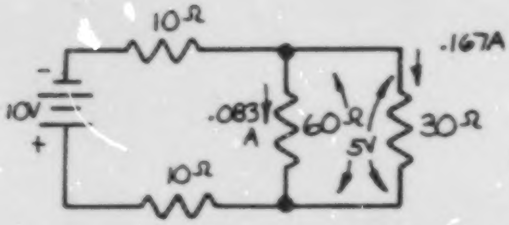
$R_t = 40\Omega$

10. $I_t = \frac{10V}{40\Omega} = .25A$


10Ω
2.5V
5V
-
10V
+
20Ω
10Ω
2.5V

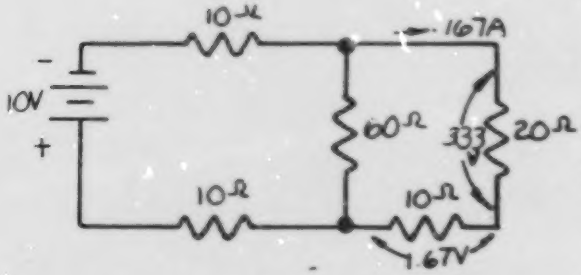
I = .25A in both 10Ω resistors and 20Ω equivalent resistance E = IR

5V = .25A x 20Ω


10Ω
.167A
-
10V
+
.083 A
60Ω
5V
30Ω
10Ω

$I = \frac{E}{R}$

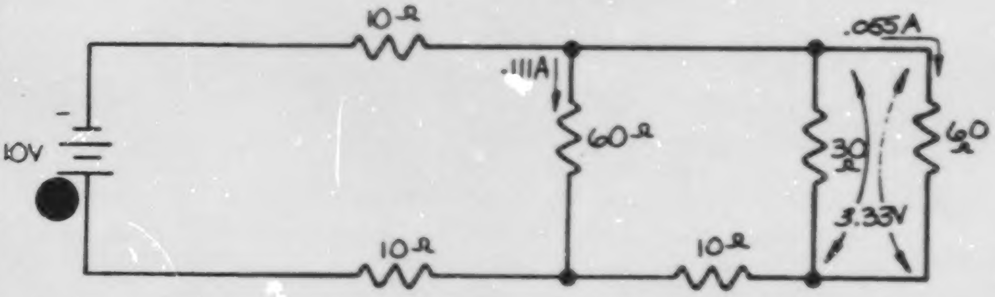
$.083 = \frac{5V}{60\Omega}$ $.167A = \frac{5V}{30\Omega}$


10Ω
.167A
-
10V
+
60Ω
3.33
20Ω
10Ω
10Ω
1.67V

E = IR

1.67V = .167A x 10Ω

3.33V = .167A x 20Ω


10Ω
.055A
.111A
60Ω
-
10V
30Ω
60Ω
3.33V
10Ω
10Ω

$I = \frac{E}{R}$

$.111A = \frac{3.33V}{30\Omega}$

$.055A = \frac{3.33V}{60\Omega}$

11. $P_{source} = 10V \times 0.25A = 2.5W$

# Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Calculated Resistance | | |
| Calculated Current | | |
| Measured Current | | |
| Current Measured in Equivalent Resistor | | |
| Final Test 85% | | |

When all checks indicate OK, proceed to the next learning package.

INSTRUCTIONAL LEARNING SYSTEMS

# 2.15

## SWITCHES AND RELAYS

### Goal:

The apprentice will be able to describe types of switches and relays.

### Performance Indicators:

1. Identify common types of switches.
2. Describe relays.

# BASIC ELECTRONICS

## Switches and Relays
## EL-BE-23

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| An assortment of switches and relays | Identify the different types of switches. |
| | Connect circuits using switches to operate lamps in different modes. |
| | Draw operational circuit diagrams using switches and relays. |
| Questions on switches and relays | Complete a Final Test with an accuracy of 90%. |

## Directions

Obtain the following:

Assortment of switches
A relay
Connecting devices
Lamp

## Learning Activities

______ Study Key Words list.

______ Read the Information Sheets.

______ Complete Task circuits and drawing.

______ Do Self-Test.

______ Do Final Test.

______ Obtain Final Evaluation.

## Key Words

Arc: A discharge of electricity through a gas (such as air).

Closed: A closed loop, a complete path; a connected circuit.

NC: Normally closed; closed in the rest position.

NO: Normally open; open in the rest position.

Open: An open loop not connected; not operational; disconnected.

Pole: The part of the switch that has the moving contact on it.

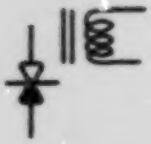
Rotary: A switch that is turned with a knob which can select any one of many contacts.

Throw: The part of a switch which has the stationary contact on it.

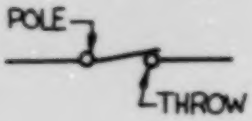
Hydraulic action: Devices that are operated by fluid flow. (Example: the brake system in the automobile.)

Bimetal action: A strip of 2-layer metal that bends as heat is applied. The bending of the strip can activate switches, etc.

Symbol for relay



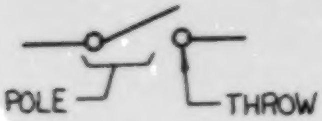
Symbol for switch



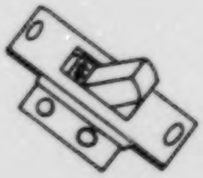
# Information Sheet

The switch is one of the most common electrical devices. We use switches every day to turn off or on our lights, appliances, and machines. Some switches are very simple. One example is the light switch that is on the wall of a home. Some switches are very complicated. These include multi-heat switches on the electric range and rotary switches that are found in radios, TV sets, and stereos.

Let's start with the most simple switch, called the SPST switch. The SPST stands for single-pole, single-throw. Below you see the symbol for a SPST switch. Next to the symbol you see what the switch looks like (pictorial).

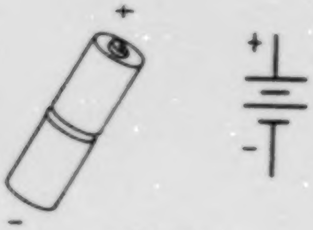


SYMBOL

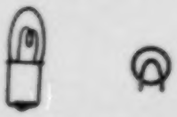


PICTORIAL

Notice that on the symbol there are one pole and one throw. Because there is only one of each, there are only two places to connect wires. On the pictorial you will notice that there are only two terminals. This will help you identify a single-pole, single-throw switch. Now let's hook this switch into a circuit. We will use symbols for the circuit components. Study the symbols and pictorials below. Be sure that you can identify each of them.

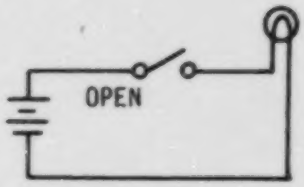


BATTERY

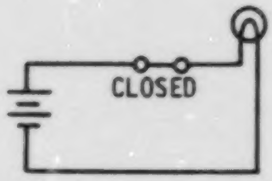


LAMP

Here are two circuits. They are the same except that the first one is shown with the switch open and the second with the switch closed.



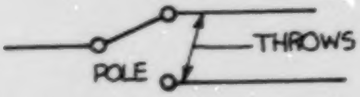
No current flow.



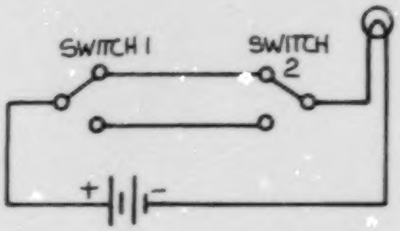
Current flow.

The circuit that is open is broken; there cannot be any current flow The circuit that is closed has a complete path for current. This makes it operational. This is the type of circuit that is found in the common flashlight.

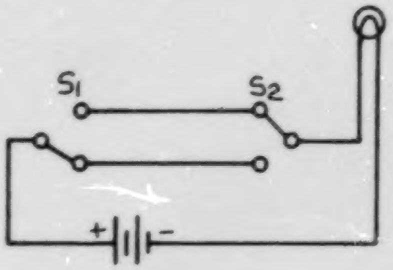
As you have learned, switches are identified by the number of poles and throws. Let's look at a single-pole, double-throw switch.



The SPST switch was good for turning one lamp off and on with one switch. How can we turn one lamp off and on with two switches? The SPDT is the switch for the job. Study the next drawings. Notice that no matter which position the switches are in, it is possible to turn off or on the lamp from one position or the other.



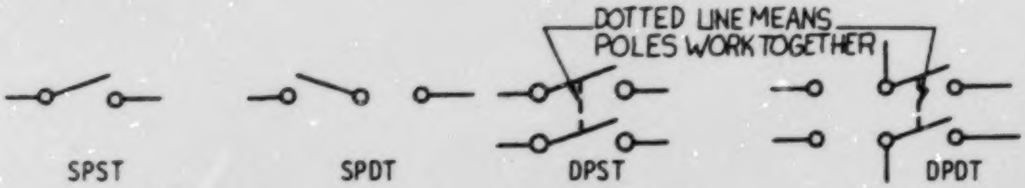
Closed



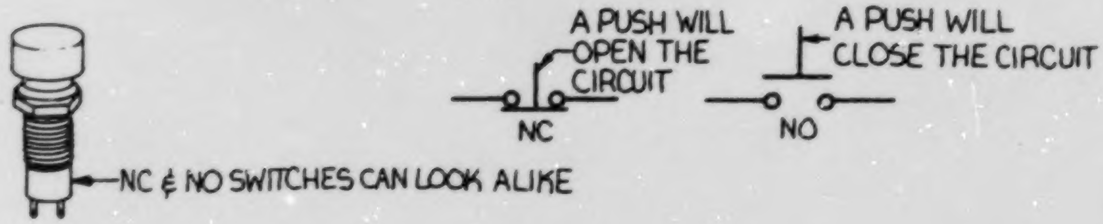
Open

When this type of circuit is used in a home, it is called a three-way switching hook-up.

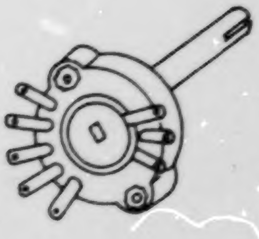
There are other switches which make it possible to turn off or on a lamp from three or more positions. The following shows the first two switches we have studied and two other switches that you may see.

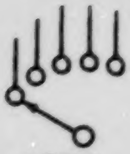

DOTTED LINE MEANS
POLES WORK TOGETHER
SPST
SPDT
DPST
DPDT

There are some switches that are made so that they return to the same position when they are released by the operator. These are called momentary-contact switches. They are normally spring loaded so that they flip back when released. Momentary-contact switches can be the normally open type (NO) or the normally closed type (NC). Pictured below are the momentary-contact-type switches.

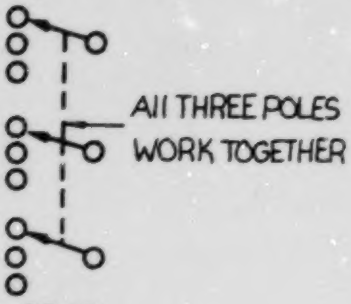

A PUSH WILL
OPEN THE
CIRCUIT
NC
A PUSH WILL
CLOSE THE CIRCUIT
NO
NC & NO SWITCHES CAN LOOK ALIKE

Another type of switch that is very common and sometimes very complicated is the rotary switch. The rotary switch may have many sets of poles and multiples of throws. The following are a few rotary-switch symbols and their names. The second P stands for position; 3P3P stands for three-pole, three-position.



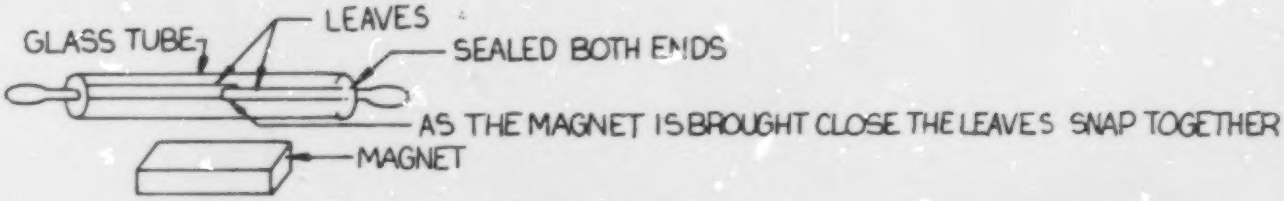


SP5P
SINGLE POLE
5 POSITION


All THREE POLES
WORK TOGETHER

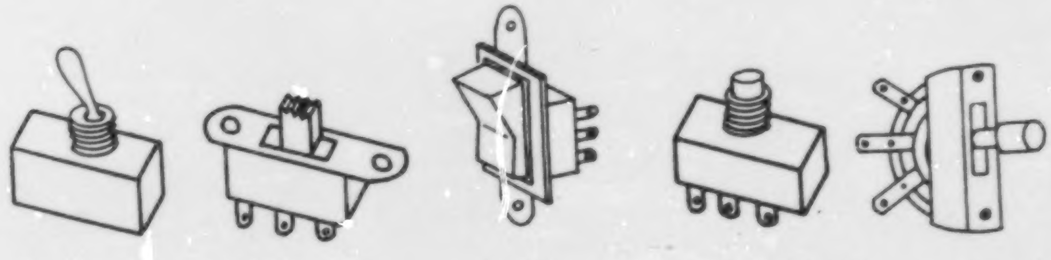
3P 3P

Another switch which is less common but very important is the reed switch. It is sealed in a glass tube and is operated with a magnet. What it looks like is shown below.



SPST NO

The outside appearances of switches vary as to their application and mounting method. Below are a few of the most common types and their names. The names refer to the mechanisms which activate them.


Toggle Slide Rocker Push Button Lever

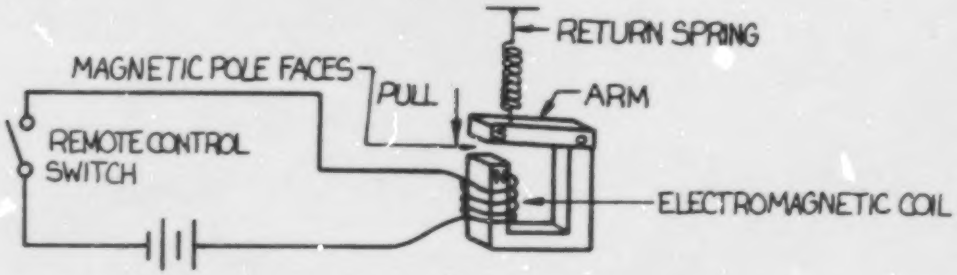
Switches are given ratings for their current and voltage capabilities. To understand why this is done, remember that whenever an electric circuit is broken, an arc occurs. This hot arc burns away at the contact points. The more current or the more voltage, the greater the arc. The contact points take most of the beating as the switch is used. These points are made of metals that are very hard and will not burn or a material that is conductive even after it is burned. The points in a car are of tungsten, a very hard material. The points in a water heater are made of silver. Silver is conductive after it has been burned. Some switches have snap actions which switch very quickly. The fast switching reduces the arc and saves the contact points.

## Relays

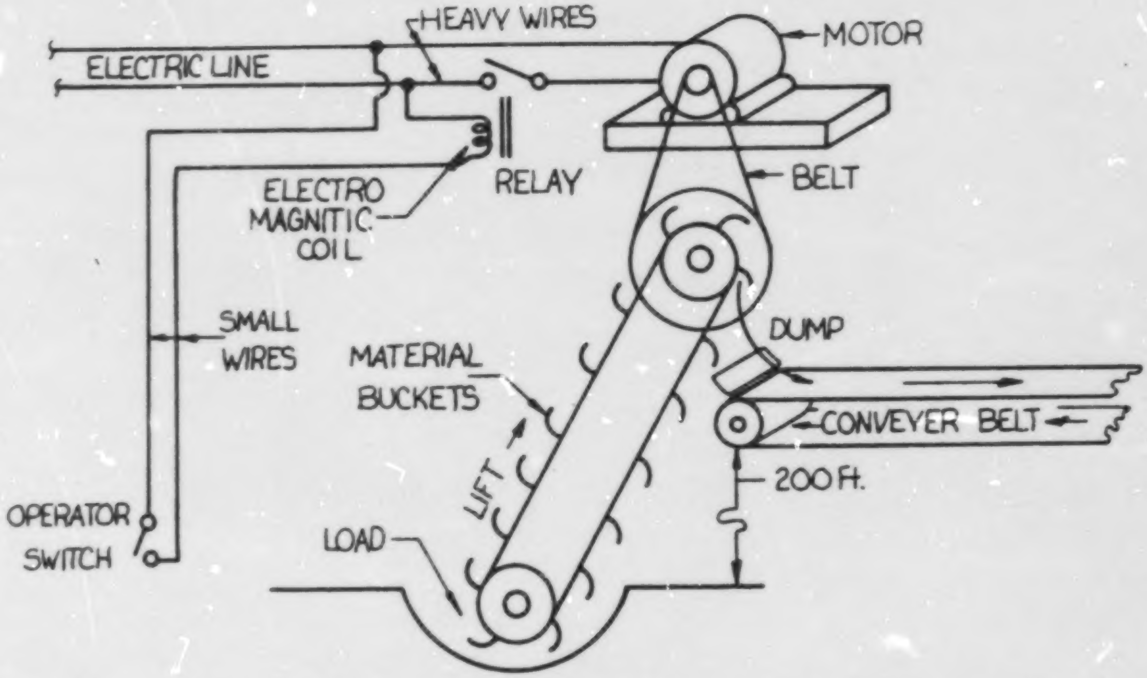
The relay is nothing more than a switch that is operated from a distance by an operator, a time clock, a radio or even a computer. Have you every wondered what turns the bell off and on at the beginning and end of the class time? Right, a relay is the switch that does the job. The time clock turns on the relay and the relay turns on the bell. You may ask, "Why do we need a relay? Can't the time clock turn on the bell?" If you think about it for a while, you will realize that there are many bells in the school building. Just think of the arcing on the contacts in the clock. Wouldn't it be better to divide up the switching into several switches for different parts of the building? Right again. The clock will last much longer if we don't overload the small timed switch inside the clock.

But just how does the relay work? Most relays work on electromagnetic action. There are a few special types that use air, hydraulic action or even bimetallic action to do the switching. Let's consider the magnetic type.

The magnetic relay, as the name says, uses magnetic energy to operate the switch contacts. The magnetism is produced by the electric current from the coil. This closes the switch and closes the circuit. When the current is off, the magnetic field collapses, which allows the return spring to lift the arm and open the switch. Study the circuit below. Notice that the electromagnet is turned on and off by a remote SPST switch.

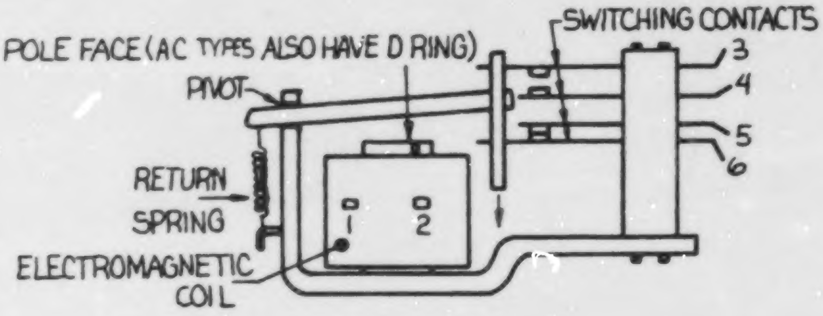


When the SPST switch is closed, the arm of the electromagnet is pulled down against the pole face with a snap. When the control switch is open (as shown), the magnetic pull stops, and the arm is pulled off the pole face by the return spring. It is this up-and-down action that is used to close and open contacts in the relay. The following circuit shows a practical set-up with a relay used to turn on and off a motor on an industrial elevator.


HEAVY WIRES
MOTOR
ELECTRIC LINE
RELAY
BELT
ELECTRO MAGNITIC COIL
SMALL WIRES
DUMP
MATERIAL BUCKETS
CONVEYER BELT
LIFT
200 Ft.
OPERATOR SWITCH
LOAD

There is an advantage in using the relay to turn the motor off and on: small wires to a small switch can control large amounts of energy.

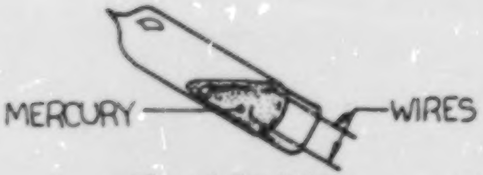
The construction of relays differs somewhat, but all of them use similar action. The drawing below shows the construction of a typical relay. Notice the set of contacts. Which ones are normally open? Which ones are normally closed?


SWITCHING CONTACTS
POLE FACE (AC TYPES ALSO HAVE D RING)
3
4
PIVOT
5
6
RETURN SPRING
1
2
ELECTROMAGNETIC COIL

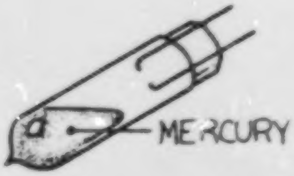
Relay with Parts Labelled

You are right! Contacts 3 and 4 are normally open (NO). Contacts 5 and 6 are normally closed (NC). Connections 1 and 2 hook to the electromagnetic coil.

Another switch that you should know about is the mercury switch. This switch is a position switch. When one side is up, the switch is off; when the other side is up, the switch is on. Study the drawing below. Is this a SPST or SPDT? How is the contact made?



Closed Position



Open Position

Right! It is a SPST switch. It has only two connections. Right again! The contact is made by the conductive mercury touching the wires in one end of the bulb.

You may have seen one of these switches in action on the trunk of a car. When the lid is open, it turns on the light. When the lid is closed, it tilts the switch which turns off the light.

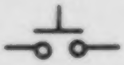
## Self-Test

Choose the correct answer.

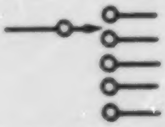
1. The A/C relay has a special ____________ on the pole face.
   - a. washer
   - b. R ring
   - c. D ring
   - d. A ring

2. The magnetism in the relay is provided by
   - a. the coil.
   - b. the contact.
   - c. the terminals.
   - d. the return spring.

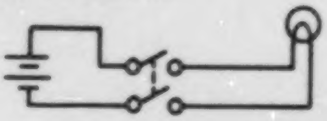
3. This push button is a ____________ type.
   - a. SPST
   - b. NO
   - c. closed
   - d. NC



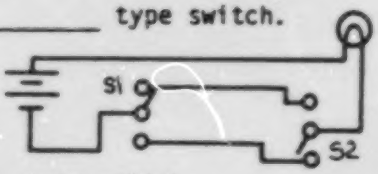
4. This symbol is for a ____________ type switch.
   - a. SPST
   - b. DPDT
   - c. SP5P
   - d. 5PSP



5. Identify the switch in this schematic.
   - a. SPST
   - b. SPDT
   - c. DPDT
   - d. DPST



6. In this drawing $S_1$ is a ____________ type switch.
   - a. toggle
   - b. rocker
   - c. SPDT
   - d. DPDT



7. SPST stands for a ____________ type switch.
   - a. single-pole, single-toggle
   - b. single-pole, single-throw
   - c. any rocker
   - d. snap

8. The snap action on some switches
   - a. helps the operator know when the switch is activated.
   - b. increases the arc.
   - c. decreases the arc.
   - d. means that the switch is new.

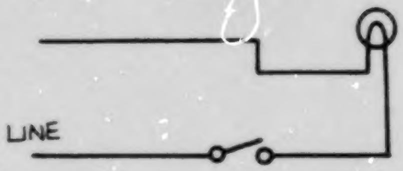
9. The mercury in the mercury switch provides
   - a. the electrical contact.
   - b. weight control.
   - c. indication of switch position.
   - d. improved appearance.

10. Silver is used on some switch contacts because of
    - a. appearance.
    - b. lower contact resistance even if burned.
    - c. smoother action.
    - d. high expense.

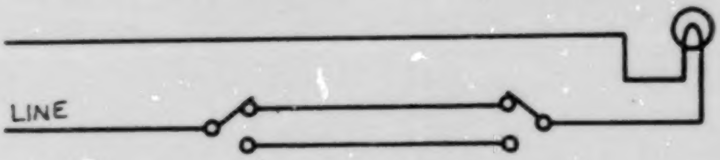
## Task

Construct and test the following circuits.

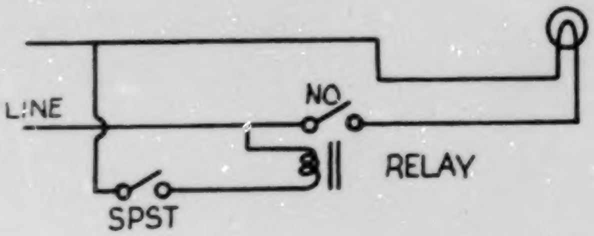
Circuit 1
Construct a circuit to turn on and off one lamp with one SPST switch. (Use schematic as a guide.)



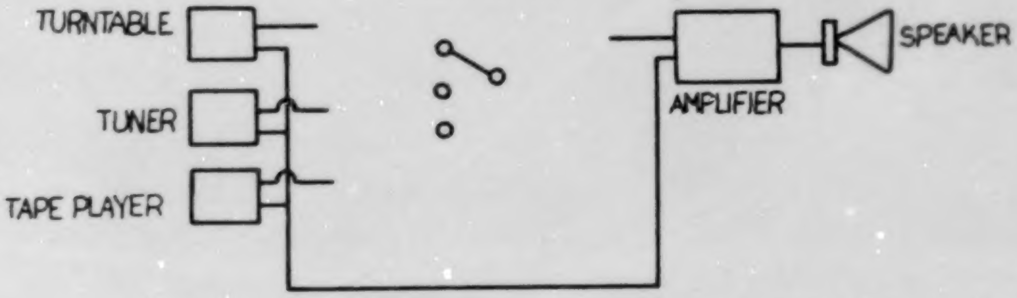
Circuit 2
Construct a circuit to turn off or on a lamp from two locations using two SPDT switches. (Use schematic as a guide.)



Circuit 3
Construct a circuit to turn off or on one lamp with a relay controlled by a SPST switch. (Use schematic as a guide.)


LINE
NO
RELAY
SPST

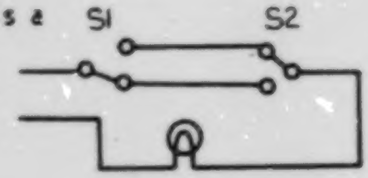
Circuit 4
Complete this drawing (schematic) using a rotary switch as a selector to connect any one of the following to an amplifier.


TURNTABLE
TUNER
TAPE PLAYER
AMPLIFIER
SPEAKER

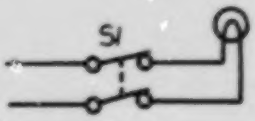
# Final Test

1. SPST stands for
   a. Single-position, single-toggle.
   b. Single-pole, single-throw.
   c. Special-position, single-throw.
   d. Any toggle switch.

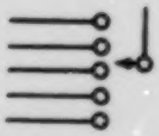
2. In this circuit drawing S2 is a
   a. a toggle switch.
   b. 4-way switch.
   c. SPDT switch.
   d. a rocker switch.



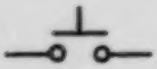
3. In this drawing $S_1$ is a
   a. SPST.
   b. DPST.
   c. SPDT.
   d. DPDT.



4. This symbol is for a __________ type switch.
   a. SPST
   b. 5PSP
   c. SP5P
   d. DPST



5. This push button is a __________ type.
   a. NO
   b. NC
   c. SPST
   d. closed



6. The coil in a relay provides
   a. D-ring mount.
   b. magnetic energy.
   c. heat.
   d. return action.

7. The D ring is found on
   a. SPST switches.
   b. normally open switches.
   c. AC relays.
   d. DC relays.

8. Why are some switch contacts made out of silver?
   a. It makes the switch more expensive.
   b. The silver keeps its conductivity even though it is burned.
   c. The action is smoother.
   d. Less heat is developed.

9. The mercury switch is a
    a. position switch.
    b. DPDT switch.
    c. thermo switch.
    d. NO switch.

10. Some switches have snap action
    a. so the operator can hear the snap.
    b. to increase arcing.
    c. to reduce ohm rating.
    d. to reduce arcing and heat.

# Final Evaluation

## Check sheet

All circuits 100% operational.
All drawing 100% correct.
A score of 90% or better on the Final Test.

| | OK | RE-DO |
|---|---|---|
| Circuit construction | ________ | ________ |
| Circuit drawing | ________ | ________ |
| Final test ________% | ________ | ________ |

When all checks are OK, proceed to the next package.

## Answers

### Self-Test

1. c
2. a
3. b
4. c
5. d
6. c
7. b
8. c
9. a
10. b

INSTRUCTIONAL LEARNING SYSTEMS

# 2.16

## BASICS OF ALTERNATING CURRENT

### Goal:

The apprentice will be able to describe the basic concepts of alternating current.

### Performance Indicators:

1. Describe flow of electrons.
2. Describe wave forms.
3. Describe cycles and frequency.
4. Describe peak and RMS voltage.
5. Describe audio generator.

# BASIC ELECTRONICS

## Basics of Alternating Current
## EL-BE-25

Test Draft
September 1981

## Acknowledgment

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## Objectives

| Given: | The student will: |
|---|---|
| A series of questions on basic AC | Answer 9 of the 10 questions correctly. |
| Ten problems dealing with RMS and peak voltages | Solve 9 of the 10 problems correctly. |
| An audio generator and head phone | Set up and operate the audio generator properly. |

## Directions

Obtain the following:

An audio generator
Head phone set (with connecting wires)
Calculator

## Learning Activities

______ Study the Key Words list.

______ Read the Information Sheets.

______ Complete the Self-Test.

______ Solve the problems on the problem sheet.

______ Do the Task.

______ Do the Final Test.

______ Obtain Final Evaluation.

# Key Words

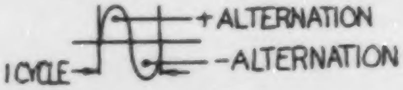
AC: Abbreviation for alternating current. Symbol: ∿

Alternation: One half of a cycle; it can be positive or negative.

Alternating current: Current that changes polarity at a regular rate.

Audio generator: A device that produces alternating current which can be changed in frequency, wave shape, and output level. This package will cover frequencies which are in the range of the human ear.

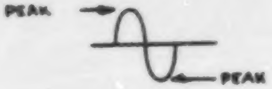
Cycle: A set of positive and negative alternations of an AC voltage.



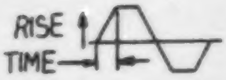
Frequency: The number of cycles in a given period of time. As an example, a frequency of 20 hertz means 20 cycles per second.

Hertz: The measure for the number of cycles per second. (Hz)

Peak: The furthest point from the center that a wave form reaches in either the negative or positive direction.

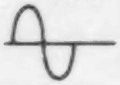


Rise time: The amount of time that it takes for a voltage to get from 0 up to peak.



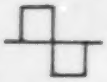
RMS: Short for root mean square. It is a value that is 70.7% of the peak value or .707 times peak.

Sine wave: A smooth, ever changing wave form. A pure frequency.

Example of a sine wave-- 

Square wave: A wave form that changes abruptly from 0 to peak value, holds at peak and then abruptly goes back to 0, reverses to a peak and returns to 0.

Example of a square wave--



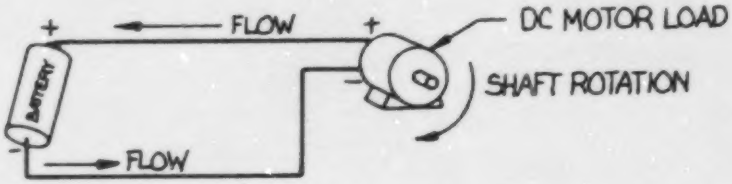
# Information Sheet

## AC and the Oscilloscope

In the last package you learned how to set up the oscilloscope and use it to take DC voltage measurements. Although taking DC measurements with the scope is important, the real advantage of using an oscilloscope is to look at voltages that change value at a fast rate of speed. Before we worry about how the scope sees these changing voltages, let's take a look at what AC really is.

## Basics of AC

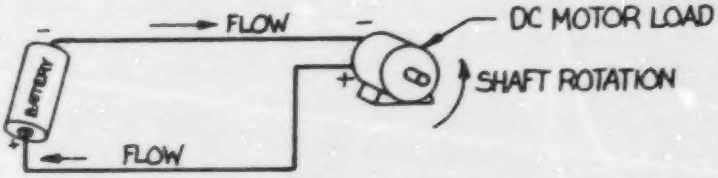
We know that DC (direct current) flows in one direction. The electrons leave the battery from the negative pole, pass through the wires and the load, then return to the battery's positive pole. The electrons are going in only one direction. Study the circuit below.



From this circuit you should recognize that:

1. This is a DC circuit.
2. The DC motor is the circuit load.
3. The motor is turning clockwise.

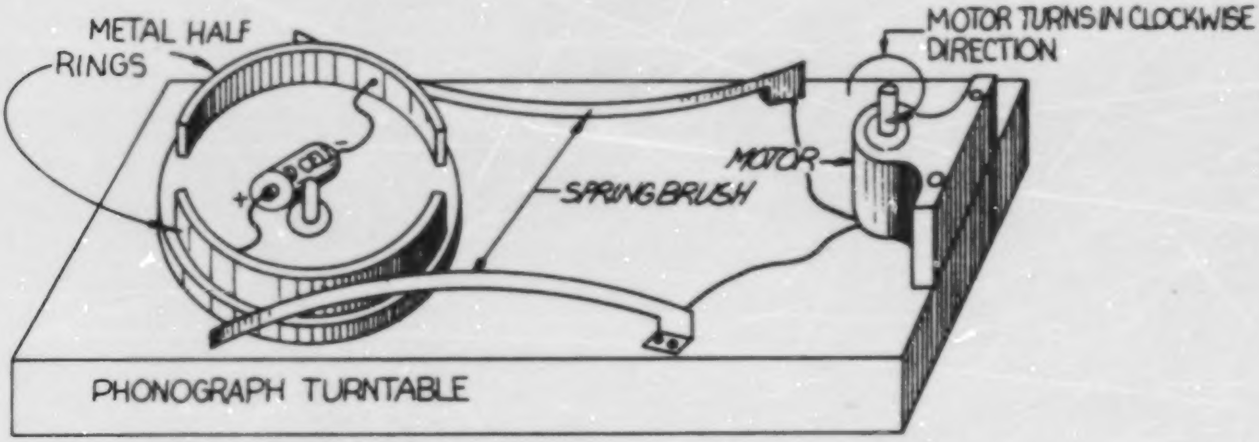
The motor can be reversed by changing the polarity of the voltage source connected to it, thus reversing the direction of the current through the load. If the battery were to be turned one-half turn, the motor would go counter-clockwise. See the circuit below.



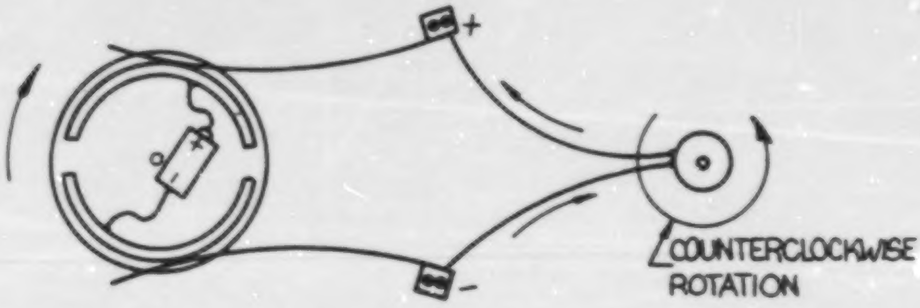
From the last drawing you should recognize that:

1. The battery is connected with the polarity reversed.
2. The current flow is in the opposite direction.
3. The motor is now turning in a counterclockwise direction.
4. The DC motor can be reversed by changing polarity.

Now let's go a step further. We will set up a circuit that will switch polarity of the battery. Study the circuit drawn below.

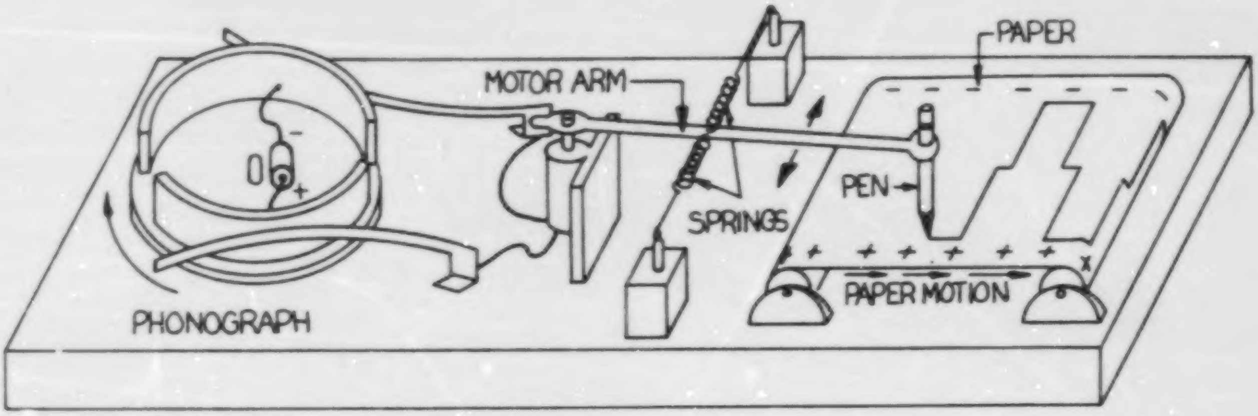

METAL HALF RINGS
MOTOR TURNS IN CLOCKWISE DIRECTION
MOTOR
SPRING BRUSH
+
-
PHONOGRAPH TURNTABLE

As the battery rides around and around on the turntable, the spring brushes slide on the metal half-rings which connect the motor to the battery. Let's look at the circuit again after it has turned one-half rotation.


+
-
COUNTERCLOCKWISE ROTATION

Now the polarity has been reversed and the motor shaft direction has also been reversed. The action that takes place is one of the motor changing direction over and over. The faster the phonograph turntable goes, the faster the motor must change directions. This changing of direction of current flow is called alternating current (AC) because it alternates polarity.

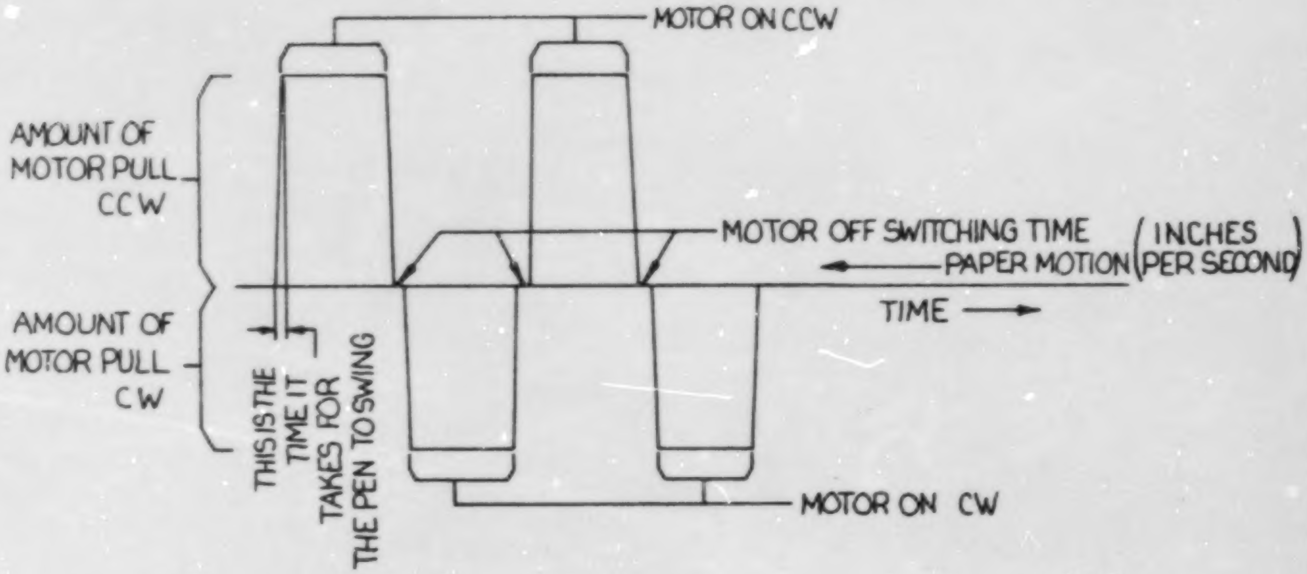
To really see what is happening in an alternating current circuit we must be able to recognize the changes of voltage and polarity in relation to time. This sounds like a big order, but if we construct a graph to show these relationships, it becomes much simpler. To get an idea of how this graph should look, let's go back to our turntable-AC current producer and connect a graph-drawing attachment to it. Study the drawing below.



From the drawing above, you should be able to recognize that:

1. As the battery rides around on the turntable, a current that is changing polarity is fed to the motor.
2. As the current changes polarity, the motor changes shaft direction.
3. As the motor tries to turn, it is limited by the springs.
4. The pen draws a line on the moving paper which shows the direction of motor shaft rotation.

The next step is to study the graph that the pen made on the moving paper. The drawing following shows the graph and what happened in the circuit to cause it.


MOTOR ON CCW
AMOUNT OF MOTOR PULL CCW
MOTOR OFF SWITCHING TIME
PAPER MOTION (INCHES PER SECOND)
TIME
AMOUNT OF MOTOR PULL CW
THIS IS THE TIME IT TAKES FOR THE PEN TO SWING
MOTOR ON CW

This graph (called a wave form) can give us much information about the circuit. Study the following list:

1. We can tell how much voltage was applied to the motor by the amount of motor pull. If the battery had more voltage, the peak wave would be higher because the motor would turn more. (The higher the wave form, the more the voltage.)

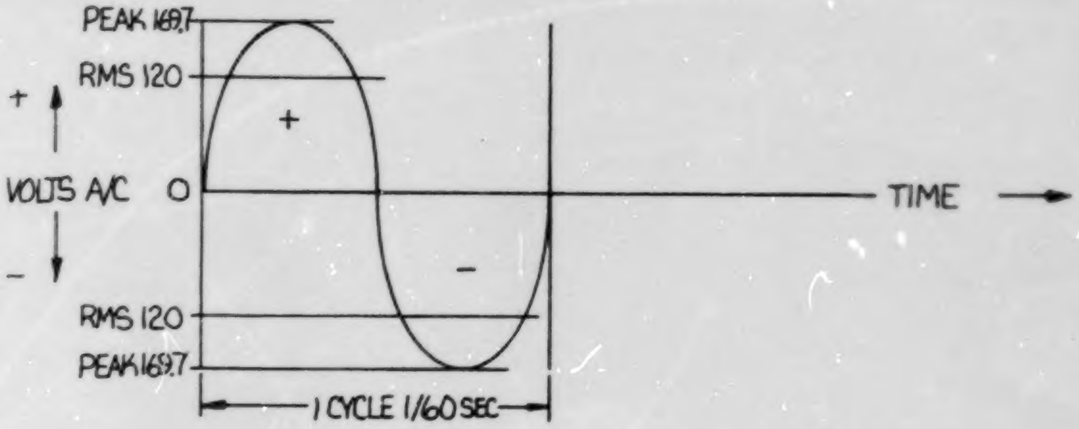
2. We can tell the current direction (polarity) by the direction of the wave from the off line. Above the off line is normally positive and below is normally negative.

3. If we know how fast the paper was moving (inches per second), we can tell how many changes of polarity took place per second.

4. The pen cannot get from the center (zero point) to the top of its swing in zero time. This slight delay makes the vertical lines slanted by just a small amount. The time that it takes for the pen to go from zero up to peak is called rise time. The amount of rise time can be measured on this graph if we know how fast the paper was traveling.

## The Sine Wave

Most wave forms don't look like the one made by our battery turntable device. The most common wave form is the sine wave. You may hear it called the pure form of any frequency. The alternating current that we get from the power company has this sine shape. The drawing below shows a sine wave similar to the ones produced by the power company. The amount of time span shown is only 1/60 of a second. This means that 60 of these take place in one second.



From the drawing of the sine wave you should be able to recognize that:

1. The sine wave is alternating current because it changes polarity.
2. The sine wave shows a smooth change of voltage from zero up to a peak value positive, then back down to zero. From zero it goes up to a peak value negative then back to zero. This all took place in a 1/60 of a second.
3. The list of events that took place in 2 above is called a cycle. Each cycle is made up of one positive alternation and one negative alternation.
4. We can measure alternating current by the number of cycles per second.
5. The peak voltage is the very top of the wave form.
6. The amount of time that it takes for a voltage to get from zero up to peak is called rise time.
7. The RMS voltage is slightly less than the peak value. (70.7% of peak.) An explanation of RMS voltage follows in the next paragraphs.

## Frequency in Hertz

As was stated before, we can measure alternating current by the number of cycles per second. The measure that is used is called frequency (how frequently a cycle takes place). Remember that frequency in hertz deals with the number of cycles per second, no other time interval. As an example, the frequency of the power line is 60 Hz. The cycles per second is understood. 60 Hz = 60 cycles per second.

## Peak and RMS Voltages

When AC voltages are measured, we have a different problem from what we had with DC. The DC voltage was the same as long as the circuit was on. With AC both the negative and the positive voltages go up and down. Why not measure the voltage at its highest point (the peak voltage)? This might sound like a good way to do it, but there is a problem. The voltage is only at the peak for just an instant. Because of this, the amount of power from a 100 volt AC circuit is less than from a DC 100 volt circuit. It was found that 100 volts peak AC produced as much power as a DC voltage of 70.7 volts. All AC voltmeters don't measure peak, but they do measure .707 times the peak. This measure is called RMS voltage. If we know the peak value of an AC voltage, we can find the RMS.

RMS = .707 X peak

Let's say that we checked the line voltage and found that it was 160 volts peak value. What would be the RMS voltage?

RMS = 160 X .707
RMS = 113.1 volts

AC voltages are almost always expressed in RMS. The line electrical outlets in our homes are called 110 volts. This is really a RMS voltage. If this is so, what is the peak line voltage? To figure this one we need another magic number like the .707. This time the number is 1.41421. This one you can find with your calculator if it has a square root sign ($\sqrt{\phantom{x}}$) on it. 1.41421 is the square root of 2.

The formula for finding the peak voltage if the RMS is known is

Peak = RMS X 1.414

Let's finish our problem. We said that the line voltage was 110 volts RMS. This means that

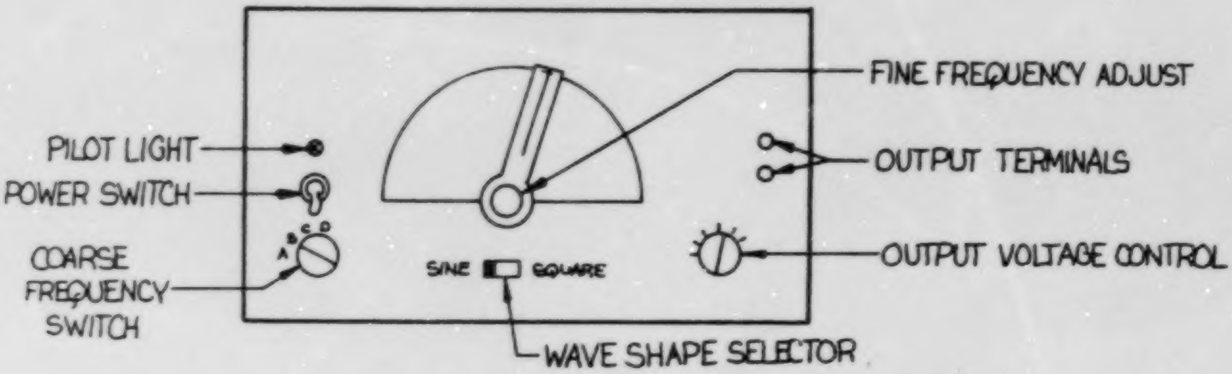
Peak = 110 X 1.414
Peak = 155.5 volts

If you are unsure about how to do this, read it again because the test will have problems dealing with RMS and peak. Refer to the sine wave figure as shown in the beginning of the discussion.

## The Audio Generator

When there is need to test a DC circuit, it is a simple matter to use a battery or a power supply. The AC circuit is a different matter. In the AC circuits it may be necessary to change not only voltage but frequency and wave shape as well. The device to do this is called an audio generator. As the name implies, it generates audio frequencies. The audio frequencies include the frequencies that can be heard with the human ear. The audio generator must include frequencies from 20 Hz to 20 kHz.

Audio generators differ somewhat depending on the manufacturer, but the controls are very similar. The following drawing is of a typical audio generator. Study the controls so you can explain what each of them does.


FINE FREQUENCY ADJUST
PILOT LIGHT
OUTPUT TERMINALS
POWER SWITCH
A
B
C
D
COARSE FREQUENCY SWITCH
SINE
SQUARE
OUTPUT VOLTAGE CONTROL
WAVE SHAPE SELECTOR

Problem Sheet

1. The line voltage was measured to be 117 volts RMS with a voltmeter. What is the peak value?

2. While working on a power supply the peak AC voltage was measured with an oscilloscope. The voltage was found to be 155.5 volts peak. What was the RMS voltage?

3. While working on the water heater in my house, I found that the voltage across the element was 225 volts RMS. What was the peak value?

4-10.
The table below represents a series of line voltages taken over a period of one week at the peak load time. Some of the readings are peak values and some are RMS values. Complete the table so that both peak and RMS values are given.

| | | Peak | RMS |
|---|---|---|---|
| 4 | Sun | | 125 |
| 5 | Mon | 150 | |
| 6 | Tues | | 109.5 |
| 7 | Wed | 146 | |
| 8 | Thurs | | 113 |
| 9 | Fri | 142 | |
| 10 | Sat | | 110.2 |

## Self-Test

1. To reverse most DC motors you must
    a. switch the shaft end to end.
    b. invert the motor.
    c. reverse the polarity of the connections.
    d. give the shaft a twist in the opposite direction.

2. The difference between AC and DC is that AC
    a. flows in one direction.
    b. switches on and off.
    c. switches polarity.
    d. has only positive alternations.

3. The rise time is
    a. the time it takes for one cycle of AC.
    b. the time it takes for the voltage to go from 0 to the peak value.
    c. the time it takes for one turn of the motor.
    d. the lag between cycles.

4. The sine wave is
    a. a smooth pure wave form.
    b. an abrupt changing wave form.
    c. a triangular shaped wave form.
    d. a sawtooth type wave form.

5. One cycle is
    a. equal to RMS times peak.
    b. one positive alternation and one negative alternation.
    c. a span of 1/10 of a second.
    d. equal to RMS minus peak.

6. RMS voltage is
    a. higher than peak.
    b. equal to the square root of two.
    c. equal to .707 times the peak value.
    d. equal to 1.414 times the peak value.

7. The audio generator produces signals in the frequency range of
    a. 10 hz to 100 kHz.
    b. 20 hz to 20 kHz.
    c. 400 cps to 5 kHz.
    d. any electric organ.

8. The audio generator's output can be controlled to
    a. change frequency.
    b. change resistance.
    c. change wave shape, voltage, and frequency.
    d. change wave shape, resistance, and voltage.

9. The AC voltmeter measures
    a. peak value.
    b. 1.414 volts less than peak.
    c. RMS voltages.
    d. .707 of the RMS voltage.

## Task

### Set-Up and Operation of the Audio Generator

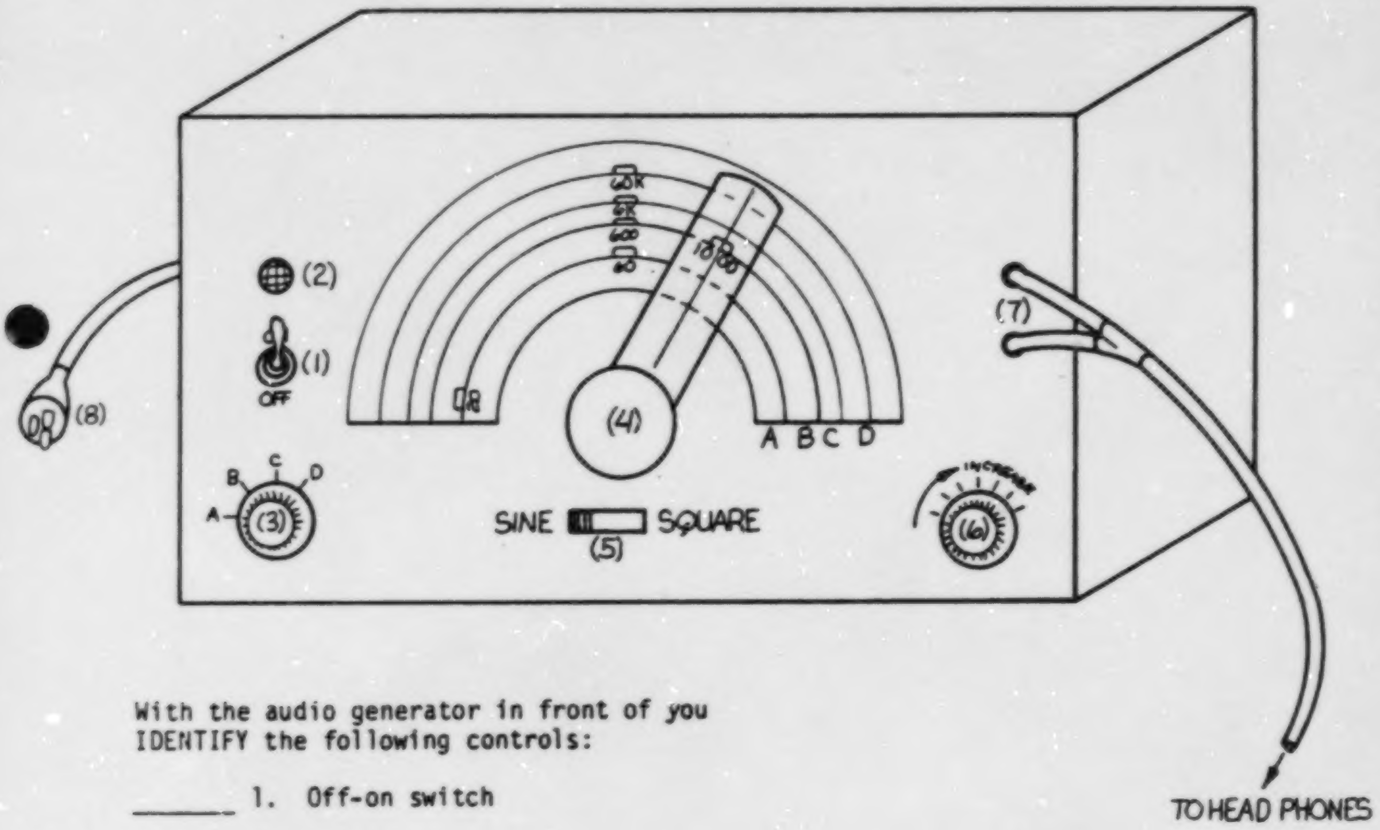
For this task you will need the following materials:

One audio generator
One pair of head phones
One set of connecting wires

### Set-Up

Refer to this drawing for all steps in this task.

(All audio generators are not alike, but they will have comparable controls.)


60K
6K
600
60
(2)
(1)
OFF
(8)
(4)
A B C D
(7)
A
B
C
D
(3)
SINE
SQUARE
(5)
INCREASE
(6)
TO HEAD PHONES

With the audio generator in front of you
IDENTIFY the following controls:

______ 1. Off-on switch

______ 2. Pilot

______ 3. Coarse frequency adjust

______ 4. Fine frequency adjust

______ 5. Wave form switch

______ 6. Output level control

_______ 7. Output terminals

_______ 8. Power cord

Operation of the audio generator

_______ 1. Plug in power cord.

_______ 2. Switch unit on (check pilot).

_______ 3. Adjust fine frequency control to 1000 Hz.

_______ 4. Switch coarse frequency to correct band for 1000 Hz (B).

_______ 5. Switch wave form to sine position.

_______ 6. Connect head phones to output terminals.

_______ 7. Place the head phones on your head with the phones slightly off ears (to avoid loud blast).

_______ 8. Adjust output level control so you can hear the sound (called a signal).

_______ 9. Turn the frequency controls to different settings. (Notice how the pitch in the phones goes up as the frequency is increased.) What is the highest frequency you can hear?

Answer the questions below.

1. What is the lowest sine frequency that you can hear? (not feel)

_________________ Hz

2. What is the highest sine frequency that you can hear?

_________________ Hz

3. How does the square wave sound different from the sine wave?

_______ Instructor check

# Final Test

1. A smooth, ever-changing pure wave form describes
   a. a sawtooth wave form.
   b. a triangular wave form.
   c. a sine wave form.
   d. a trapezoidal wave form.

2. In an AC wave form, the time that it takes for the voltage to go from 0 to the peak value is known as
   a. one cycle.
   b. an alternation.
   c. the rise time.
   d. the fall time.

3. AC is different from DC because AC
   a. flows in one direction.
   b. switches on and off.
   c. switches polarity.
   d. has longer cycles.

4. To make a DC motor reverse directions
   a. reverse the polarity of the connections.
   b. invert the motor.
   c. reverse the motor shaft end to end.
   d. give the shaft a twist in the reverse direction.

5. The major advantage of the oscilloscope is its ability
   a. to measure DC power levels.
   b. to see changes that happen at a fast rate of speed.
   c. to measure DC voltages.
   d. to measure DC current level.

6. The output of the audio generator can be changed
   a. as to its voltage.
   b. as to its voltage and wave shape.
   c. as to its voltage, resistance, and wave shape.
   d. as to its voltage, frequency, and wave shapes.

7. The normal AC voltmeter measures
   a. RMS voltage.
   b. peak voltage.
   c. .707 of the RMS value.
   d. 1.414 times the peak value.

8. The frequency range of the audio generator includes
   a. 20 Hz to 20 kHz.
   b. 10 Hz to 400 Hz.
   c. 1Hz to 10000 kHz.
   d. 1kHz to 2kHz.

9. RMS voltage is
    a. equal to .707 times the peak value.
    b. equal to 1.414 times the peak value.
    c. equal to the square root of two.
    d. the same as the peak value.

10. One cycle of alternating current is
    a. one span of 1/10 of a second.
    b. equal to RMS times peak.
    c. one positive alternation and one negative alternation.
    d. equal to RMS minus peak.

| | OK | RE-DO |
|---|---|---|
| Completed Task | __________ | __________ |
| Completed problem sheet with 90% or better _____% | __________ | __________ |
| Completed Final Test with 90% or better _____% | __________ | __________ |

When all checks indicate OK, proceed to the next learning package.

**Answers to Problem Sheet:**

1. 165.5 V peak
2. 109.9 V RMS
3. 318 V peak
4. 177
5. 106
6. 155
7. 103
8. 160
9. 100
10. 156

**Answers to Self-Test:**

1. c
2. c
3. b
4. a
5. b
6. c
7. b
8. c
9. c

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INSTRUCTIONAL LEARNING SYSTEMS

# 2.17

## MAGNETISM

## Goal:

The apprentice will be able to describe permanent and electromagnetism.

## Performance Indicators:

1. Describe permanent magnets.
2. Describe magnetic fields.
3. Describe laws of repulsion and attraction.
4. Describe magnetic flux.
5. Describe electromagnetism.

# BASIC ELECTRONICS

## Magnetism
## EL-BE-45

Test Draft
September 1981

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## Objectives

| Given: | The student will: |
|---|---|
| A list of questions about basic permanent magnetism and electromagnetism. | Answer questions on the final test with an accuracy of 90 percent. |
| A set of magnetic equipment. | Identify magnets and magnetic polarity. Wind a solenoid and an electromagnet and test each. |

## Directions

Obtain the following:

Set of magnets
Compass
Magnetic cores
#18 wire
Paper or cardboard tube
Power supply
Box of nails

## Learning Activities

______ Study Key Words list.

______ Read Information Sheets.

______ Do Self-Tests.

______ Do Task A.

______ Do Tasks B and C.

______ Do Final Test.

______ Obtain Final Evaluation.

## Key Words

Coil: A spiral winding of wire.

Core: The center part of a coil, made of a magnetic material or air.

Domain: Very tiny magnetic area in iron, nickel, or cobalt.

Electromagnet: A coil of wire powered by a source of electricity.

Field: The magnetic flux around a magnet.

Flux: The lines of magnetic force around a magnet.

Gauss: A unit that is used to measure the amount of magnetic force.

Keeper: A piece of iron across the poles of a magnet placed there to prevent loss of magnetism when the magnet is in storage.

Line of force: Referring to the magnetic flux.

Magnetic metals: Iron, nickel, and colbalt.

Magnetic polarity: Referring to the north- and south-seeking ends of a magnet.

Magnetomotive force: The magnetic push.

Pole: The end of the magnet, where the magnetic force is greatest.

Residual magnetism: The magnetism that remains in a metal after the magnetic force has been removed.

Saturation: The point at which a piece of magnetic material cannot be further magnetized.

Solenoid: A coil without a core. A sucking coil.

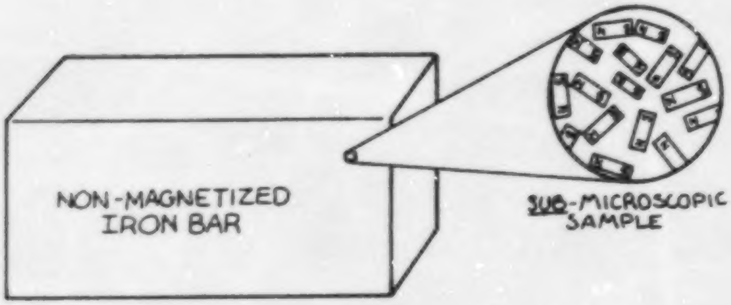
# Information Sheet No. 1

## Permanent Magnets

Magnetism is involved in a great number of electric and electronic devices such as motors, solenoids, transformers, meters, etc. A knowledge of the basic principles of magnetism is important for understanding the operation of these devices.

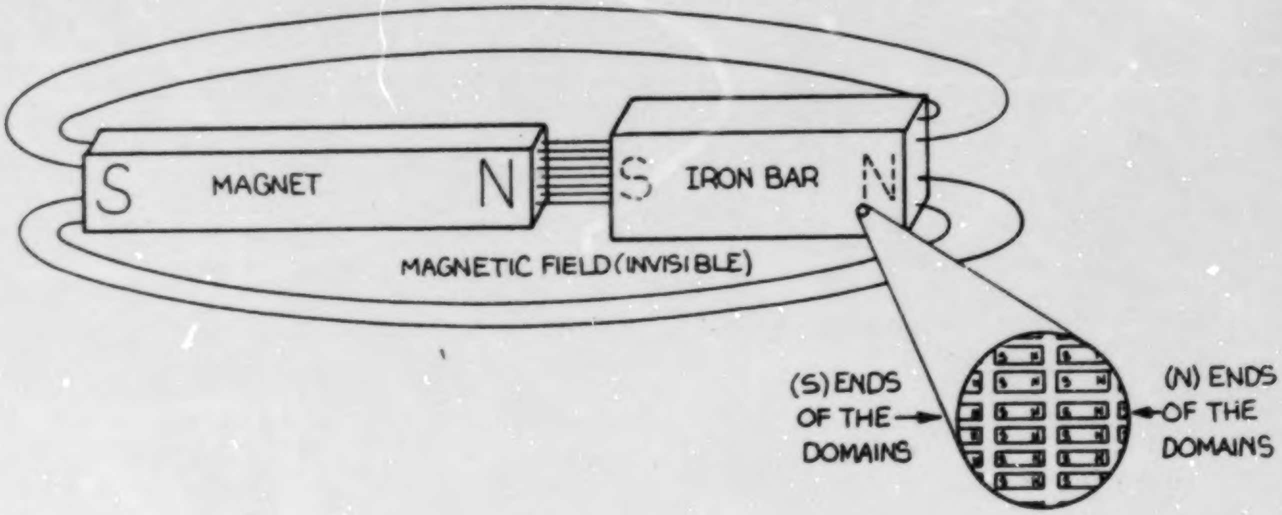
There are only three magnetic materials on earth. A magnetic material is a material that can be attracted by a magnet. These materials are iron, nickel, and colbalt. Materials like steel are alloys that contain iron; therefore, they are magnetic.

The simplest magnet is a bar magnet. One end of the magnet is labeled N and the other end is labeled S. All you have to do to understand the N and S is to make a compass out of the bar magnet. The end that points north is stamped N and the end which points south is stamped S. So when we say the north end of a magnet, we mean the north-SEEKING end. What makes a magnet want to point north and south? No one has the answer to that question. The exact nature of magnetism is not really known, but we are aware of the actions of magnetic materials. If we look into a piece of iron with a magnetic eye, we will see a lot of tiny magnets called domains, pointed every which way all over inside the material. Remember that these domains are only in the three magnetic materials: iron, nickel, and colbalt. The shape of the domain is not really known, but we will picture it as a tiny bar. These domains can turn and spin around in the material. The drawing below is a domain grouping inside a non-magnetized iron bar.



Notice that the domains are pointing every which way. The total effect is that the N end of each domain is facing a S end of another domain. This cancels out the external magnetic force so the bar of iron is not a magnet.

If the bar of unmagnetized iron were put into a magnetic field (next to a magnet), the domains inside of the iron would align themselves with the magnetic field. Study the drawing below.

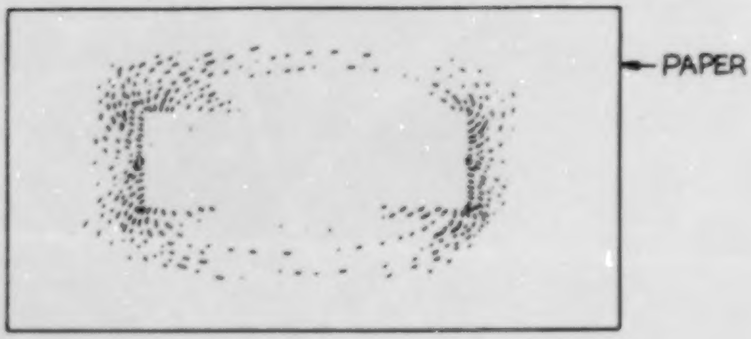


The magnetic domains in the iron are lined up so that the S ends are pointing toward the N end of magnet. This causes the magnet to attract the iron and makes a temporary magnet out of the iron bar. (Notice the dotted S and N indicating that the magnetism is temporary.) When the magnet is removed from the iron bar, the domains will spin around to cancel out the magnetism. The iron turns back to the nonmagnetized state.

If there were some way that the domains could be locked into the magnetized condition, the iron bar would remain a magnet. This is impossible with soft pure iron. The addition of carbon, copper, aluminum, colbalt, and nickel to the iron produces an alloy which will lock the domains so they cannot turn. This means that a permanent magnet is a special alloy of metals. The magnet must have special handling because heat or jarring will tend to unlock the domains, which will destroy the magnetic effect.

## The Magnetic Field

The magnetic field, sometimes called a flux field, is the invisible force around a magnet. This force is very common. Because the earth is a magnet, we live in magnetic fields all the time. When we walk, we are going through these magnetic lines. How can we detect or see magnetic lines? One way is to take a bar magnet, place a sheet of paper over it, and sprinkle iron filings on the paper. The following drawing shows what the result would look like.

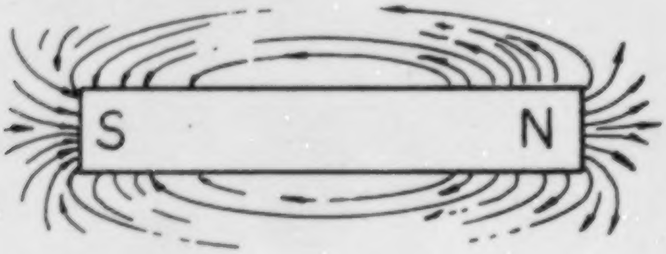


IRON-FILING PATTERN OVER A BAR MAGNET

From the iron-filing pattern, it is hard to see the full picture of the lines of force. What can be seen is that:

1. The ends or poles have most attraction.
2. There are two poles.
3. There seems to be no magnetic action in the center.
4. The force field seems to be in lines from one end to the other.

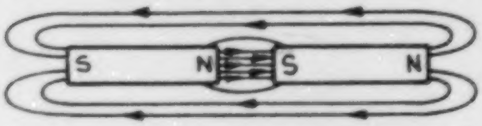
In the following drawing the magnetic flux is shown again, but this time it is shown more clearly than could be done with the iron filings. (Only a small amount of lines are shown to make the drawing clear.)



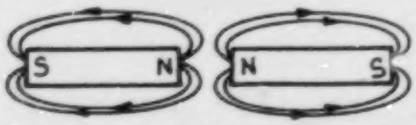
This drawing shows that there are distinct lines of magnetic flux. Each has direction from the N end of the magnet to the S end. These lines are also complete (continuous) from the north to the south end.

## The Magnetic Laws of Attraction and Repulsion

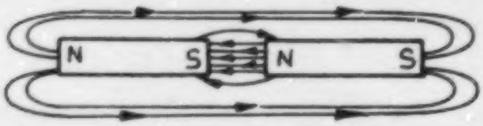
As was stated before, the N end of the magnet tries to point north. This means that there is an attraction to the north pole of the earth. This makes the compass (which makes use of a magnet) very important for navigation. What is happening to the flux lines during the attraction? Study the drawings of the magnets below.



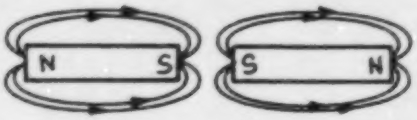
Attraction
North to South



Repulsion
North to North



Attraction
South to North



Repulsion
South to South

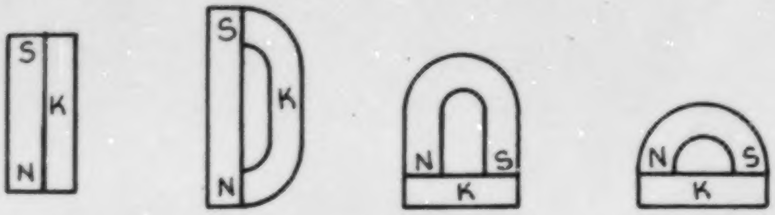
Knowledge of the directions and form of these magnetic fields is very important for understanding the operation of devices such as speakers, tape-recording heads, etc.

From the drawings you know that:

1. Unlike magnetic poles attract. (North and a South or South and a North)
2. Like magnetic poles repel. (North and a North or South and a South)
3. When the poles attract, the flux lines from one magnet combine with the flux lines from the other magnet.
4. When the poles repel, the magnetic flux lines do not combine.

## Keepers

The magnetic flux passes through materials with different amounts of resistance. As an example, the magnetic flux passes through iron much more easily than through air, plastic, etc. For a magnet to last a long time, the gap between the north and south poles should be as small as possible. When the magnet is not in use, it is wise to place a bar of soft iron between the poles. This bar of iron is called a KEEPER. The magnets pictured below have keepers on them.



Magnets with Keepers

## Measuring the Magnetic Flux

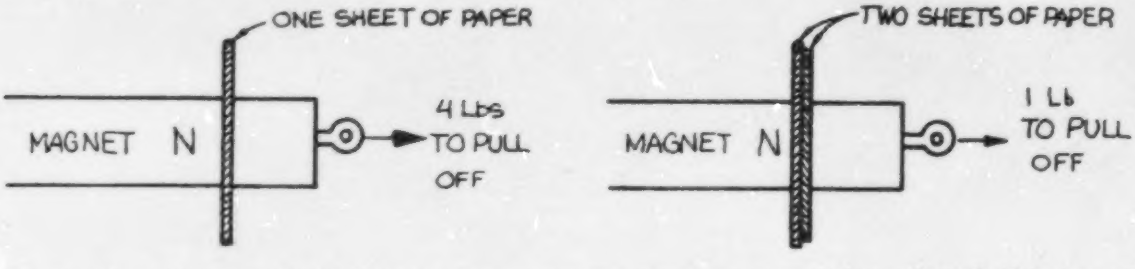
How strong a magnet is depends on many factors. Some of these factors are the following:

1. The mass of the magnet (amount of metal).
2. How well it is magnetized.
3. The alloy of the metal.
4. Its shape or form.

The more lines of magnetic flux per area, the more magnetic effect we can get. The measure of magnetic flux concerns the number of lines. There are at least three systems of measurement of magnetic flux: Gauss, Maxwell, and the Weber. Gauss is a measure of the number of lines of a magnet. The Weber has to do with the amount of flux change per second to produce one volt induction. As a point of comparison, the earth's field is less than one Gauss while a small toy horseshoe magnet could have 200 Gauss!

## The Square Law Magnetic Relationships

Study the drawing below that shows tests of magnetic pull.



Each time that you double the distance between the magnetic pole of the magnet and the magnetic material, the magnetic pull decreases by the square of the distance. This means that as you move away from a magnet, the flux level drops at a fast rate. This is very important when dealing with tape heads of a tape recorder. A very small amount of dirt can hold the tape far enough from the head to make the tape unit completely inoperative. Keeping the magnetic gap clear on a tape head is very important.

## Self-Test No. 1

1. The magnetic field is sometimes called

   a. magnetic force.
   b. flux lines.
   c. iron filings.
   d. north and south.

2. The direction of magnetic fields is

   a. around the magnet in a crosswise direction.
   b. from the north pole to the south pole.
   c. from the south pole to the north pole.
   d. along the sides of the magnet.

3. The law of magnetic attraction and repulsion states that

   a. like poles repel and unlike poles attract.
   b. like poles attract and unlike poles repel.
   c. the south pole attracts another south pole.
   d. the square of the north pole equals the square of the south pole.

4. If a block of soft iron is 1 cm from a magnetic pole and then moved to .5 cm, the force between them will

   a. double.
   b. halve.
   c. quadruple.
   d. triple.

5. The flux lines around a magnet are

   a. in both directions.
   b. more dense as you move away from the pole.
   c. complete from the south pole to the north pole.
   d. complete from the north pole to the south pole.

6. The strength of a magnet in the center section halfway between the poles is

   a. equal to the square of the north pole.
   b. zero.
   c. four times stronger than at the poles.
   d. weaker in larger magnets.

7. The strength of a magnetic field is measured in

   a. volts per inch.
   b. Gauss or Weber.
   c. flux line diameter.
   d. the square Maxwell.

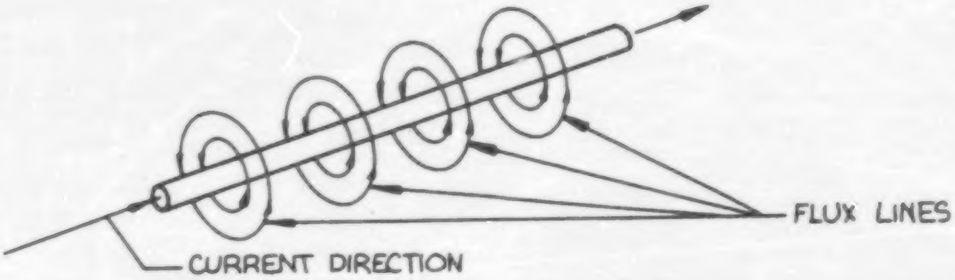
8. The following materials are magnetic

   a. lead, tin, and zinc.
   b. gold, silver, and copper.
   c. aluminum, chromium, and platinum.
   d. iron, nickel, and colbalt.

# Information Sheet No. 2

## Electromagnetism

There is a relationship between magnetism and electricity. One of these relationships is that whenever current is passed through a conductor, a magnetic flux is set up around the conductor. The form that the magnetic flux lines make is one which surrounds the wire in a sheath. Study the drawing of the current-carrying conductor.

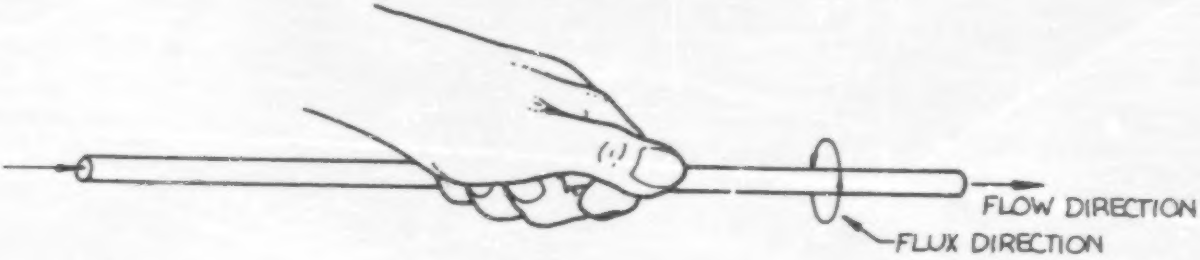


The Magnetic Flux around a Wire

From the drawing you should be able to recognize that:

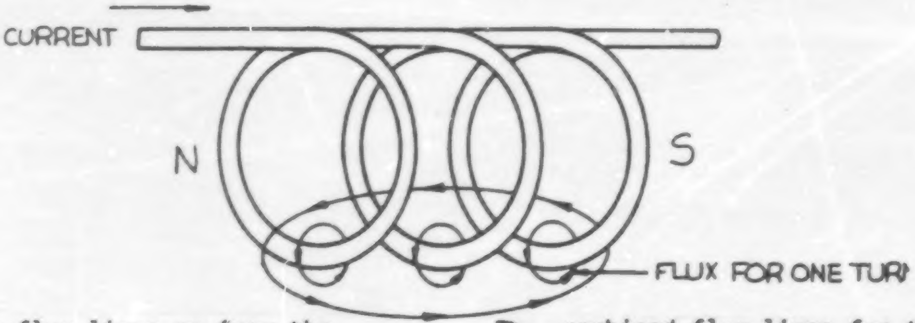
1. The current-carrying conductor has a magnetic flux around it.
2. The magnetic flux is around the wire in a crosswise direction.
3. The magnetic flux is continuous all along the wire.

If you know the direction of the current flow through the wire, you can tell the direction of the magnetic flux around the wire by the use of the LEFT-HAND RULE. The following drawing shows this method.



Grasp the wire with the left hand with the thumb pointing in the direction of the current flow. The fingers will wrap around the wire in the direction of the magnetic flux lines. Also, if the fingers were to be wrapped around in the direction of the magnetic flux, the thumb will point in the direction of the current flow.

The amount of magnetic flux around one wire is quite small. To make a stronger flux field, we can concentrate the wire by winding it into a coil. To picture how the coil can concentrate the flux, study the drawing of the coil below.



The flux lines go from the north end to the south end on the OUTSIDE of the coil.

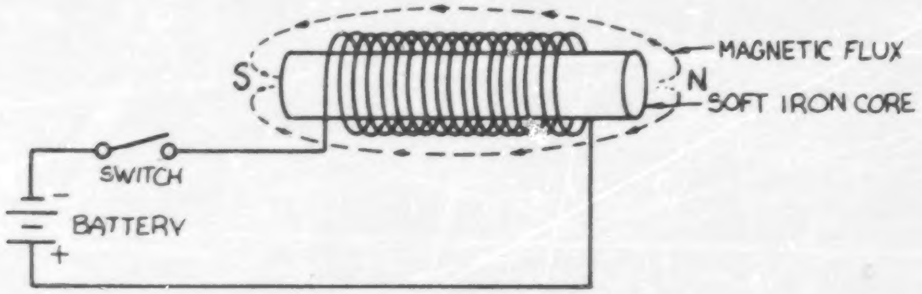
combined flux lines for the coil

From the drawing it can be seen that the flux lines around each turn of the coil can combine with the flux lines from the next turn. All of the flux lines will combine to form a magnetic flux for the coil. Check it out with the left-hand rule. The more turns of wire in the coil, the stronger the magnetic effect. Notice from the drawing that the magnetic polarity is shown. This too can be seen. Remember that the flux lines go from the north end of the magnet to the south end ON THE OUTSIDE OF THE MAGNET. Check it out on the drawing.

## The Electromagnet

Now that we know how the coil works, we can make an electromagnet. First, we need a core. The core should be a magnetic material. Iron is the strongest of the three and also the most inexpensive. Because we want to turn the magnetism off, we need a form of iron that won't let the domains lock up. Remember, soft iron is the best choice here because the domains are free to spin around and cancel the external flux lines. The iron will concentrate the lines close to the coil to give us the best magnetic effect.

To construct the electromagnet we wind the wire around the core in a neat spiral of insulated wire so the windings will not short from one to the other. Study the drawing of the electromagnet.

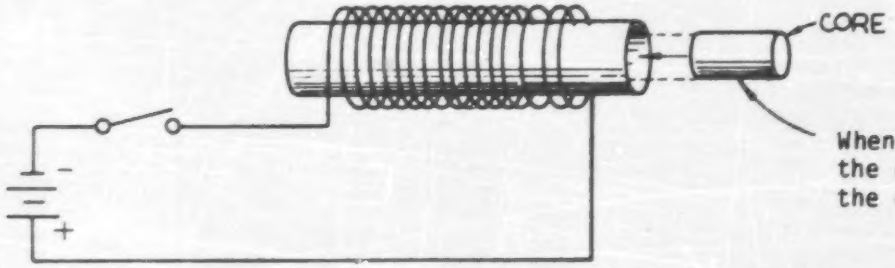


The Electromagnet

The magnetic action in and around the electromagnet is much the same as that of the permanent magnet except that the electromagnet can be turned off and on and can be many times stronger.

The Solenoid

Another type of electromagnet which is very useful is called a solenoid. The solenoid is an electromagnet without a core. The part that makes it interesting is that it seeks or attracts a core when it is turned on. To make a solenoid you wind the insulated wire around a hollow nonmagnetic tube. The tube can be made of paper, plastic, or even a metal such as copper or brass. Study the drawing of the solenoid below.



When the coil is turned on, the core will be sucked to the center of the solenoid.

The Solenoid "Sucking Coil"

Because of the mechanical travel that the solenoid can produce, it is used to do the following things:

1. Turn switches off and on.
2. Control draft and air flow in heating and ventilating systems.
3. Shift gears.
4. Operate door chimes.
5. Start or stop machines.

## Factors of Magnetism

There are many measures and factors of magnetism. Included here are a few of the most important ones.

## Magnetomotive Force (MMF)

Magnetomotive force is explained as the force needed to produce a magnetic field. This force can be made stronger by increasing the number of turns of wire on the coil or by increasing the amount of current through the coil. The ampere turn is used with magnetomotive force as a unit of measure.

## Saturation

Saturation refers to the state of a core which cannot be further magnetized. More magnetomotive force will not increase the amount of magnetism of a saturated core. This condition takes place when all of the domains in the core are lined up. It is at this point that more energy cannot increase the domain alignment so the core is said to be saturated.

## Residual Magnetism

Residual magnetism is the magnetism that remains after the magnetomotive force is removed. This condition is caused by a few of the domains staying locked in one direction. This residual magnetism can cause problems. As an example, a relay can stay stuck down after the current is turned off.

## Demagnetizing

Demagnetizing is the process of removing the magnetic effect from a material or device. Many times tools will become magnetized and will need to be demagnetized. Tape recorder heads often need to be demagnetized.

The device that is used to demagnetize is nothing more than a large coil with no core. The power to operate the coil is AC. To operate the unit the power is turned on to the coil. This produces a magnetic field that switches polarity back and forth. The object to be demagnetized is placed into the coil. The object is forced to be magnetized first one way and then the other. The object is then slowly removed from the coil. The strength of the back-and-forth reversing field becomes less and less. This leaves the object with no residual magnetism.

# Self-Test No. 2

1. If a current is flowing through a wire

   a. a magnetic field around the wire will be present.
   b. no magnetic action is present.
   c. one end of the wire is north and the other south.
   d. the heat from the wire destroys the magnetic effect.

2. Electromagnets are made by winding wires into coils because

   a. it produces less heat.
   b. the core is easy to install.
   c. the leads are easy to connect.
   d. it concentrates the magnetic field.

3. The left-hand rule for conductors

   a. is used for checking wire temperature.
   b. is used so the right hand is free to write voltage readings.
   c. shows the flux direction if the current direction is known.
   d. is more accurate than the right-hand rule.

4. A solenoid is sometimes called

   a. an electromagnet.
   b. a sound generator.
   c. a sucking coil.
   d. a long cored coil.

5. Saturation is

   a. the point at which more magnetomotive force cannot produce more magnetism from a core.
   b. the point at which the coil cannot pick up moisture from the air.
   c. the peak voltage point.
   d. caused by the residual magnetism.

6. A solenoid is used for

   a. heating soldering irons.
   b. controlling temperature.
   c. mechanical movement of pulling.
   d. measuring resistance.

7. Demagnetizing is best done with

   a. a hammer.
   b. a strong light.
   c. a large AC coil.
   d. twisting the metal one half turn north.

## Task A

Given: Four unmarked magnets, a compass.

1. Identify the north- and south-seeking ends.

   (Use masking tape to make labels.)

   When using the compass, keep it at least one inch away from the magnets' poles.

   ☐ Instructor's Check

Given: Two bars of iron with no markings:

one unmarked magnet
one unmagnetized iron bar

2. You must present the magnet to the instructor in five minutes.

   Rules: 1. No other metal object may be used.
   2. No compass can be used.
   3. You may not try to make a compass from the bars.

   ☐ Instructor's Check

## Task B

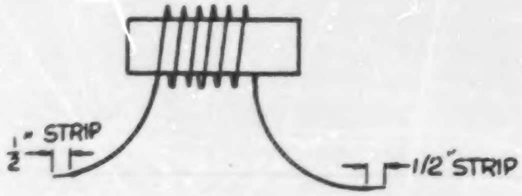
Given: Iron core, paper tube, #18 magnet wire, and a heavy power supply.

1. Construct the following solenoid:

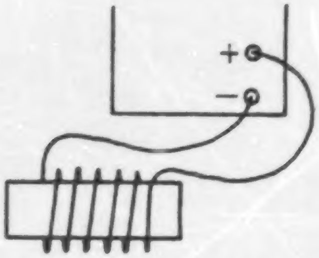
Wind 30 turns of #18 magnet wire on the paper tube. The wire must be closely wound in a neat spiral.

Leave 10 inches of wire at each end of the coil for leads. (Tape each end of the coil to hold the wire.)

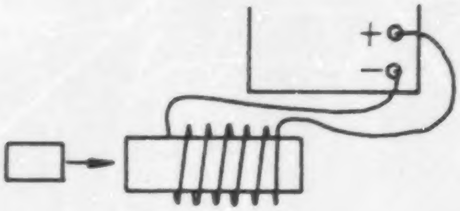
Strip one-half inch of insulation off the end of each lead.



Apply 3-5 volts to the coil from the power supply. (Don't overheat the coil.)



With the power applied to the coil, place the core into the coil.



Explain what happened.

☐ Instructor's Check

## Task C

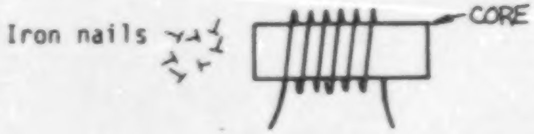
Given: Iron bar, #18 magnet wire, small box of nails, and a power supply.

1. Wind 40 turns of wire on the iron bar in two layers of 20 turns each.

   Leave 10 inches of wire for leads.

   Strip ends as in Task B.

   Tape the coil to hold the wire.



2. Apply power as called for in the chart below.

3. Count the nails that it is possible to pick up with the coil at each voltage level.

| Volts | Number of Nails |
|---|---|
| .5V | |
| 1V | |
| 5V | |
| 10V | |
| 15V | |

Work fast; the coil will become hot!

4. Did the core become saturated?

☐ Instructor's Check

# Final Test

1. The Gauss and the Weber are both measures of

   a. current levels in a coil.
   b. magnetic force.
   c. the Maxwell.
   d. volts per inch.

2. The lines of magnetic force have direction from

   a. the south end to the north end of a magnet.
   b. the poles to the center of the magnet.
   c. the north end of the magnet to the south end.
   d. the center of the magnet to the poles.

3. The three magnetic metals are

   a. iron, copper, and zinc.
   b. iron, aluminum, and nickel.
   c. iron, colbalt, and tin.
   d. iron, nickel, and colbalt.

4. If two magnets are brought together, the following action could result:

   a. the like poles will repel.
   b. heat will be produced.
   c. the two north poles will attract.
   d. no action will take place.

5. If an iron bar is brought to within one inch of a magnet and then moved to two inches away, what will happen to the pull?

   a. It will double.
   b. It will be reduced by four times.
   c. It will be reduced by one-half.
   d. It will be the same.

6. The left hand rule for conductors is used to

   a. check wire temperature.
   b. show the direction of magnetic flux.
   c. measure voltage.
   d. count the flux lines.

7. A solenoid is a coil that

   a. provides heat.
   b. is used as a holder for soldering irons.
   c. pulls the core to the center of the coil.
   d. has a permanent iron core.

8. Coils of wire are used for electromagnets because

   a. they produce less heat.
   b. they hold the core better.
   c. the leads are easy to connect.
   d. they concentrate the magnetic flux.

9. If the core of an electromagnet becomes saturated

   a. it must be thrown out.
   b. it cannot be magnetized to a higher level.
   c. it must be dried out.
   d. it has reached the domain level.

10. To demagnetize a tool or part

   a. a large AC powered coil is used.
   b. a heater must be used.
   c. a sharp hit with a hammer will do it.
   d. a strong light will do it.

# Final Evaluation

| | OK | RE-DO |
|---|---|---|
| Completed Task A | ______ | ______ |
| Completed Task B | ______ | ______ |
| Completed Task C | ______ | ______ |
| Completed Final Test with 90% score ________% | ______ | ______ |

When all checks indicate OK, proceed to the next learning package.

# Answers

## Answers to Self-Test #1

1. b
2. b
3. a
4. c
5. d
6. b
7. b
8. d

## Answers to Self-Test #2

1. a
2. d
3. c
4. c
5. a
6. c
7. c